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Andrews, Richard A.

Weyrick, Richard R.

New Hampshire Agricultural Experiment Station

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An Application of Linear Programming to Water Resources Planning

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PREFACE

This report is the final technical report submitted to the Office of Water Resources Research, United States Department of the Interior, in fulfillment of contract number 14-31-0001-3160, C-1713. The Agricultural Experiment Station, Durham, New Hampshire, provided state matching and additional supporting funds to this project.

It should be recognized that this is a normative analysis which deals with optimal situations and does not inventory the current resource use at the time of the study.

The authors express their appreciation to Wayne Eddy and Otis Perry for the huge amount of work they put into literature review, data development, and modeling while project assistants. The authors wish to thank Robert Shaw, Superintendent of the Keene Public Works Department, and the personnel of the New Hampshire Water Supply and Pollution Control Commission for providing helpful consultation and data from their files. To the many other technical, administrative, and planning people consulted, the authors express their thanks. The authors bear the responsibility for any errors in the report.

The work upon which this publication is based was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Resources Research Act of 1964, as amended.

HIGHLIGHTS, SUMMARY, AND CONCLUSIONS

Objective and Method of Analysis

The objective of this study was to evaluate the economics of various uses and cost allocation of surface-water resources in southern New Hampshire. A linear programming model for a river basin was developed to include almost all water-related economic activity for both consumers and producers. The model was so designed that the entire basin or basin subdivision could be analyzed. Within each area, externalities were internalized. The model included seven sectors: (1) rural domestic, (2) private water-based recreation, (3) public water-based recreation, (4) agriculture and forestry production, (5) intensive residential, (6) urban, and (7) industrial. In addition, a public (government) and a private sector were identified.

More than nine water-related, objective function criteria could be optimized. These included: (1) private consumer benefits, (2) private production benefits, (3) private consumer benefits plus private producer benefits, (4) private cost, (5) public cost, (6) private cost plus public cost, (7) private benefits less private cost, (8) net benefits or private consumer and producer benefits less private and public cost, and (9) environmental quality as measured in minimum biochemical oxygen demand or coliform bacteria count. The research was confined primarily to the Ashuelot River Basin, in four configurations: the northern area, the central area, the southern area, and the entire basin.

Three river-flow levels were included in the analysis. These were for the month of August and represented high- (90th percentile), median- (50th percentile), and low- (10th percentile) flow levels. The flow levels for July, September, and October exhibited a similar flow-level pattern to August.

Two river-water quality classifications were analyzed. The classes of water quality in New Hampshire range from A, the highest class, to D, the lowest class. The northern area of the Ashuelot Basin is class B. The central and southern areas were essentially class C but were reclassified B in the late 1960's. The analysis also included projections of population to 1980.

Conflicts and Objectives Optimized

The economic basis for conflicts among sectors over the incidence of cost allocation and the level of economic activity can be traced to some chosen objective or goal. The objective of minimizing *public cost*, or the minimizing of taxes and other publicly raised funds, shifted the cost of providing water supply and waste-water treatment from the public sector to the private sector. When *private costs,* the costs to industry and consumers, were minimized, the cost of providing water and water treatment was shifted to the public sector. *Minimizing public and private cost* combined limited economic growth and development as did *maximizing environmental quality* by minimizing either coliform bacteria or biochemical oxygen demand. *Maximizing environmental quality* was more costly than minimized public and private cost subject to the water-quality constraints and present economic activity in the basin.

Maximizing consumer and producer benefits less public and private costs, or *maximizing net benefits*, provided the most efficient guideline for evaluating various use and cost allocation of surface water and approximated growth potential. Minimizing public and private costs for providing water supply and waste-water disposal, by nature of the constraints on the model, approximated 1970 economic activity in the basin. These two objectives provided the basis for most of the analysis.

In all cases examined and analyzed, more water-supply and waste-water treatment facilities were shown to be needed beyond those presently found in the Ashuelot Basin. In spite of this fact, the disposal of untreated household waste water, particularly from rural households, directly into the river was consistent with maximizing net benefits in all cases except low river-flow conditions and median August, B-class level of river-water quality. At high-flow levels for August and for B-class level, this direct discharge of raw sewage into the river was economically optimal for many rural households and for some of the small communities found along tributaries. These economic optima of net benefits are not consistent with the objective of no untreated sewage being directly discharged into the river. It appears then that neither internalizing externalities, tax levies based on damages to some second party, nor quality standards would achieve this latter goal.

River-Flow Level, Classification, and Projected Influences

At high-flow levels (high precipitation), the river appeared to have untaxed assimilation capacity. As river flow decreased, more treatment facilities and more effective treatments were required. The implied price for one pound of BOD (biochemical oxygen demand) at the median-flow level based on maximizing net benefits to the basin reached 56 cents per pound for current quality levels and $7.08 per pound at low levels. At these lower flow levels, the assimilation capacity of the river is taxed.

During the low river-flow months, perverse procurement and waste-water treatment activities resulted when net benefits were optimized. The Ashuelot River, located in western New Hampshire, was used for water supply by Keene and small communities for purposes of *reducing* BOD and coliform bacteria through the use of treatment facilities. Small communities, called intensive residential areas, shifted from public treatment to septic tank treatment to further reduce BOD and coliform bacteria discharged into the river. The incidence of costs also varied between median- and high-river flow.

Measures for increasing river flow during periods of low flow were evaluated based on maximized net benefits. The results indicated that 1,000 gallons of water for flow augmentation were worth about five cents in terms of imputed variable costs.

The Ashuelot River waters in the central area were reclassified B class in the late 1960's. For analysis purposes all waters below the Surry Mountain Dam were assumed to have been classified B-class level in the late 1960's. During a low-flow period there is some question if this level of quality can be attained. During these low-flow periods, the current quality level was attainable by reducing tanning manufacturing output. This reclassification, with decisions based on minimizing public and private cost, would mean an increase in basin operating costs of about 30 percent; if based on maximizing net benefits, only 10 to 20 percent.

At all flow levels, costs and extent of treatment were allocated to those sectors with lowest costs. For each area, including the basin, constraints were the same for all sectors, and the imputed costs for meeting these quality constraints were the same for all sectors. As river-flow level decreased or as quality class increased, the imputed cost of waste-water treatment also increased. The imputed variable cost was 12 cents per pound of BOD for median river-flow level of B class, with current economic activity. This cost increased to 14.6 cents when population was projected to 1980 and to $4.15 under the assumption of economic expansion (maximizing net benefits) and with projected 1980 population. All sectors included in the analysis were affected in the incidence of costs.

Sensitivity analysis indicated that the optimal level of resource allocation was quite stable at each flow level. The resource allocation, water-treatment plants, farms, and industry changed considerably with flow level. This fact indicates that in planning waste-water treatment facilities, the river-flow level must be specified. Also, if water-quality standards are to be enforceable, some level of flow must be specified. This feature is particularly important for the months of July, August, September, and October.

For each of the three industries analyzed separately (paper, wool, and tanning) public treatment of industrial waste water was the optimal treatment process in one or more of the analytical solutions, and usually occurred at the median-flow level. This indicates that some combination of public and private treatment of waste water would result in the lowest cost. Although economies of size were included in the analysis, further economies could be achieved through coordinated effort in waste-water treatment. Coordinated activity in river-water management has economic foundation and may be necessary if a quality of B-class waters is to be attained.

Lake Resources

Most lakes in the Ashuelot Basin, as well as those in all of southern New Hampshire, are hydrologically separated from rivers by dams, which are used primarily for regulating the height of the lake. The main exceptions are reservoirs used for water supply, and flood-control structures. Most lakes are used and managed for recreation purposes. Shoreline was the dominant feature determining lake resource valuation. Implied capital value varied from $126 per foot to more than $250, depending on the discount rate. Recreation land, including shoreline, was imputed at a price of more than $15,000 an acre at the high end of the scale. Lake-surface valuation was determined by boating and swimming activities. Imputed prices on lake surface ranged from $42 to $147 an acre, depending on location and discount rate.

Beach activity was the strongest competitor for recreation resource use. Strong economic forces encouraged small lot sizes for vacation cottages with shoreline. Sizeable increases in the prices of shore lots over those of 1967-68 were indicated, and are in fact being observed now.

Vacation cottages without shoreline were strong competition for the remaining recreation land. The analyses suggest that with the current institutional arrangement lakes will resemble a picture framed by a city block as recreation land is fully developed. Observation of numerous lakes in southern New Hampshire supports this kind of conclusion. The analyses also indicate that, once a lake has been developed for recreational purposes, reversing its use for flow regulation or water-supply source would be very expensive and probably politically prohibitive. Because of the physical nature of any lake, shift in use would mean variations in lake-water level.

Lamprey River Basin

To obtain supporting information and to achieve more generality of application, a limited analysis was made for the Lamprey River basin, which is located in southeastern New Hampshire. Essentially the same results were obtained for this eastern basin as for the Ashuelot River basin. This was due to many similarities between the two basins. Both analyses used the same prices and technical information. Constraints were changed to reflect economic activity in the Lamprey River basin and the inter-basin transfer of water from the Lamprey to the Oyster River. Variation in river flow has a greater effect on resource use than quantity of water transferred.

Major Conclusions

1. The application of linear programming models to water-related activities on a river-basin basis is a valid and useful means of assessing the impact of changes in certain variables and planning objectives on optimum resource allocation. Toward this end, the linear programming capabilities for shadow pricing and sensitivity analysis are quite effective. The results appear to be indicative of real-world situations, and the model is adaptable to other river basins with a relatively small amount of additional modeling input; most changes involve adaptation of constraints to new conditions.
2. The study clearly pointed out the advantages, even the necessity, of integrated planning for water-resource development and use on a regional or river-basin basis. Economic efficiency as well as environmental quality are enhanced through combined planning and development.
3. The study identified economic conflicts that occur in choosing among water-use and -development alternatives. These conflicts must be identified before good choices can be made.
4. The analyses carried out in the study pointed out the difficulty of meeting certain environmental goals unless adequate economic and technological planning is done very soon.

CONTENTS

VALUES AND COST ALLOCATIONS OF SURFACE-WATER USE AND TREATMENT

An Application of Linear Programming to Water Resources Planning

by

Richard A. Andrews and Richard R. Weyrick[1]

PART I. INTRODUCTION

Water has ceased to be a free resource in almost all areas of organized human activity. The cost of a glass of water served with a meal purchased in a restaurant is not free. The cost of the water appears in the bill as a hidden cost of operating the restaurant. This analogy is an excellent one in the economics of water use, for there are at least social cost and benefits, if not always private costs and benefits, associated with virtually all surface-water use. These costs, although sometimes priced as an independent item, are often hidden or associated with some other resource- and water-using activity. In general, benefits and costs associated with water-resource use are elusive. Concern for environmental quality, particularly with respect to surface-water resources, has put pressure upon public policy and group action. Knowledge of these elusive benefits and costs associated with improved environmental quality and indicators of economic forces at work aid in balancing the trade-off between environmental quality, costs, and benefits derived.

The objective of this study was to investigate means of evaluating costs and benefits of use of surface waters. When one visualizes a given area of lakes and at least one river, numerous alternatives exist as to how these resources may be allocated and the water quality managed. For example, one firm may be able to effectively treat its wastes at a lower cost than could be done in the municipal treatment plant or by another firm by producing a different commodity or employing different technologies.

[1]Respectively, Professor of Resource Economics and Associate Professor of Forest Resources, Institute of Natural and Environmental Resources, College of Life Sciences and Agriculture, University of New Hampshire, Durham, New Hampshire.

To include as many interfaces of water-resource use as possible, the basin-wide firm concept developed by Timmons,[1] and Kneese and Bower[2] was employed. The basin-wide firm concept is essentially combining all firms into one decision-making unit (as if by merger), and this one decision-making unit would allocate all resources. To extend this basin-wide firm concept, households and communities were included as a part of the basin-wide firm. A linear programming model reflecting the many users and uses of surface waters was developed for optimization. Model variations were employed to cover two water-quality levels, three river-flow levels, and change in water-use patterns due to projected population increase by 1980.

1.1 Plan of this Report

This report is presented in nine parts which are, in order of presentation: (1) model and method of analysis; (2) influence of objective optimized on resource allocation, level of economic activity, and water use; (3) resource allocation and implied prices for lake and lake-related land resources; (4) resource allocation and implied prices for various river-flow levels; (5) influence on resource allocation among three areas of the Ashuelot River basin taken separately; (6) effect of improving the water-quality level; (7) sensitivity of resource allocation and implied prices to price changes; (8) comparison of two river basins; and (9) projection of change in resource use to 1980.

The Ashuelot River, located in western New Hampshire and shown diagrammatically in Figure 1.1, was chosen for detailed analysis. The Lamprey River, located in eastern New Hampshire, was chosen for comparison purposes.

1.2 Description of the Ashuelot Watershed

The Ashuelot River drains an area of 394 square miles over its 65-mile length. In the northern headwaters region in Marlow, New Hampshire, the watershed is sparsely populated, with a moderate amount of logging, and there is considerable private and public recreational activity. The city of Keene in the central portion, with a 1970 population of 20,500, is the major shopping and business center for the southwestern area of New Hampshire. Keene contains numerous manufacturing activities and an institution of higher learning. South of Keene are the small mill towns of Troy, Winchester, and Hinsdale. Several major water-using industries are found here, including two paper mills, a tannery, and a textile mill. The river ends in Hinsdale, New Hampshire, where it has a confluence with the Connecticut River. From origin to source, the river falls about 2,000 feet. The slope of the fall is rapid in the upper and the lower portions of the river. In the central portion, the river falls relatively little, and the rate of flow is rather slow. A graph of the rate of fall of the river is shown in Figure 1.2. Eight impoundments of water, including one major flood-control impoundment, Surry Mountain Dam, are located on the river.

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[1] Timmons, J. F. "Economic Framework for Watershed Development," *Journal of Farm Economics*, Vol. 46, No. 5, pp. 1170-1183, 1954.

[2] Kneese, A. V., and Bower, B. T. *Managing Water Quality: Economics, Technology, Institutions*. Baltimore: The Johns Hopkins Press, 1968.

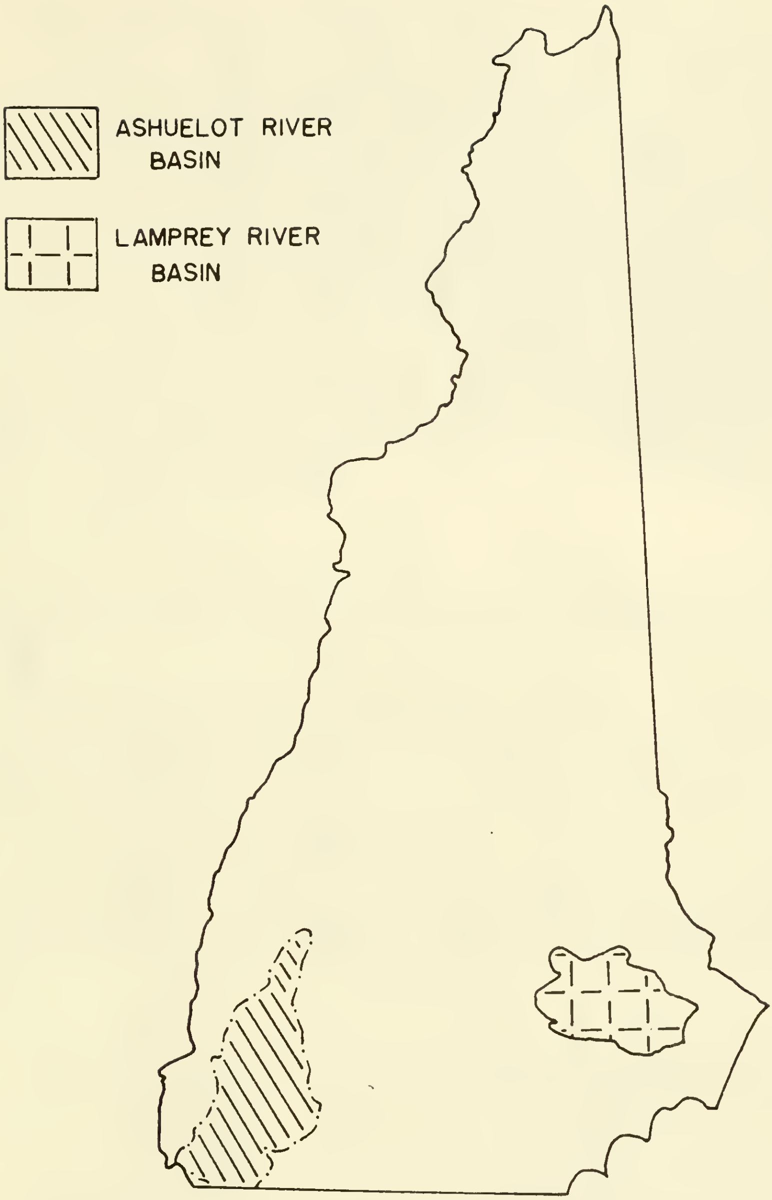
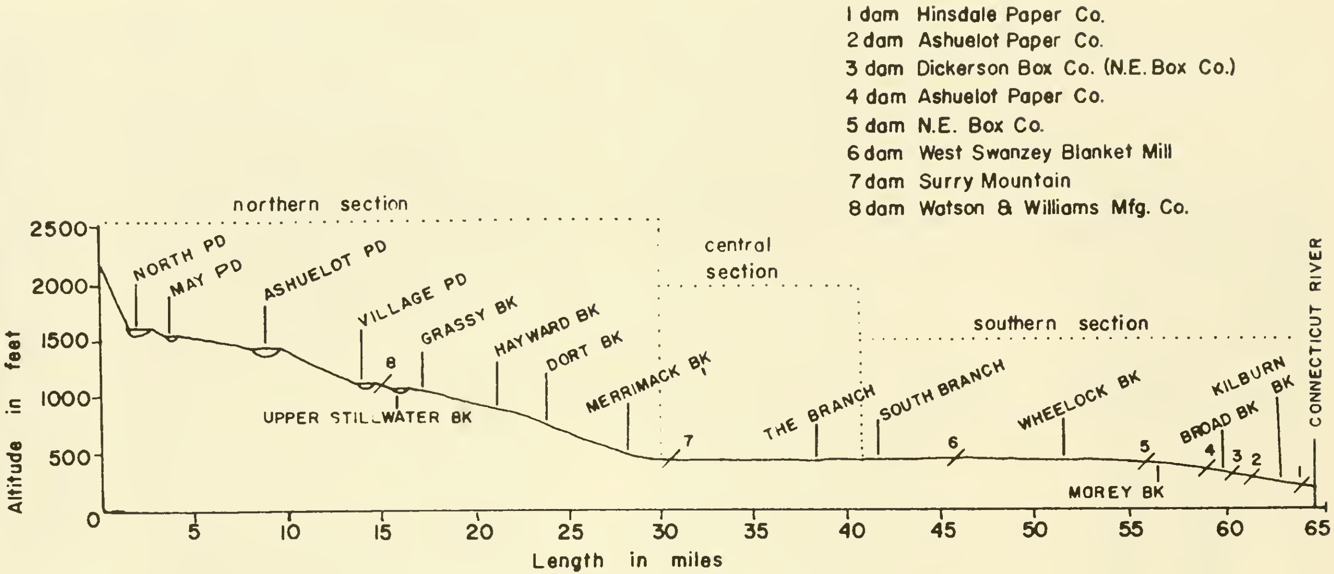


FIGURE 1.1

ASHUELOT AND LAMPREY RIVER BASINS, NEW HAMPSHIRE



Adapted from:
Biological Survey of the Connecticut Watershed
Survey Report No. 4
N.H. Fish and Game Dept., Dec. 1939, page 22

FIGURE 1.2
PROFILE of ASHUELOT RIVER, NEW HAMPSHIRE

1.3 Surry Mountain Dam

The Surry Mountain Dam was built during the time period of 1939 to 1942 by the Corps of Engineers to reduce flood damage. Prior to the dam's construction major flow damage was experienced, particularly in the years 1927, 1936, and 1938. Since the construction major damage resulting from flooding has been substantially reduced. In more recent years impoundment of water has been maintained behind the Surry Mountain Dam, and this forms a nucleus for recreational activity, including picnicking, water-related activities, and camping. An analysis of flood-control projects by G. B. Rogers,[1] and G. B. Rogers, W. F. Henry, and G. E. Frick,[2] indicates that benefits arising from the flood-control project on agriculture have been incorporated into the general economy.

Only the recreational features of the Surry Mountain Dam complex have been included in the analysis, and they were treated as a public sector recreational activity based on lake-oriented activities. The flood-control features of the Surry Mountain Dam, now 30 years old, are still contributing benefits to the area but are taken for granted. Analysis of these features of the structure is beyond the scope of this study.

1.4 Source of Data

The data employed were entirely from secondary sources. Three aspects of the data were issues of concern: the first dealt with the existence of the data, the second with the quality of the data, and the third with the units of the data.

Sufficient data concerning water, supply, and related land use did exist and, fortunately with regard to quality, a sufficient number of studies has been made by independent agencies for similar communities and areas so that comparison tests could be made. But before the comparison could be made, the data were adjusted for area, economies of size, annual and seasonal variation, and (in the case of prices) common time of occurrence.

For the communities and areas included in this study, at least one study (and, for most, two studies) of water supply and use has been made, with proposed programs for meeting the demand for potable water and waste-water treatment. Many of these studies were made during the mid or late 1960's. A description of data sources and data management is provided in Appendix A.

1.5 Some Model Assumptions

Biochemical oxygen demand, coliform count, and (in certain cases) suspended solids were the only water-quality constraints considered in the model. It was assumed that mineral and toxic materials will not be disposed of in waterways

[1] Rogers, George B. *Effects of Flood Control Projects on Agriculture: I. Reservoir Areas.* Durham, New Hampshire: University of New Hampshire, Agricultural Experiment Station, 1958. Bulletin 449.

[2] Rogers, George B., Henry, W. F., and Frick, G. E. *Effects of Major Floods and of the Surry Mountain Dam on Agriculture, Ashuelot River Valley, New Hampshire.* Durham, New Hampshire: University of New Hampshire, Agricultural Experiment Station, in cooperation with U.S. Department of Agriculture, Farm Economics Research Division, 1958. Agricultural Economics Research Mimeograph No. 21.

without treatment. The nutrient disposal, mainly nitrates and phosphates, similarly will be controlled. Conflicting evidence, coupled with lack of monitoring type of information available from secondary sources, prevented the inclusion of these items in the model.

The level of aggregation used in the study at the industry level was to consider one industry as one activity rather than taking each firm independently. At the community level, villages were aggregated into one sector or land area if they all occurred in the same region and in the same river basin. The city was aggregated on the basis of the urban activity and taken up as urban activity, rather than as individual sectors of the urban population and industry. The location of economic activity and physical features were defined by dividing the basin into areas and by natural or physical features.

All information used was compatible among the secondary sources used and converted to a 1967-68 time period for benefits and costs, and to 1970 for cultural activities.

PART II. MODEL AND METHOD OF ANALYSIS

One basic linear programming model was developed so that, through appropriate changes in the constraint vector and objective functions, many aspects of the problem could be analyzed.

The model consists of 132 equations and 218 activities. The activities include water use, water pollution, water-pollution treatment, and transfer activities from one use to another. The constraint equations include equations governing the amount of water required or the amount of water used by an activity, the pollution level created by the activity, and a water-flow account which constrains the amount of water in the river. The model is hydrologically tied together by the river-flow level and the constraints on coliform bacteria and biochemical oxygen demand.

In order to simplify data collection and to broaden the analysis, the Ashuelot River basin was divided into three separate sections, each of which comprises a geographic area within the basin. The boundaries for these areas were chosen by locating logical separating points along the river for control points regulating river-water flow and quality (see Figure 2.1). The downstream boundary of the Northern Area is the United States Geological Survey's gauging point at Surry Mountain Dam. All of the Ashuelot River basin north of that gauging station that drains through the gauging station is included in the Northern Area. The downstream boundary of the Central Area is Quality Control Point No. 16, established by the New Hampshire Water Pollution Control Commission, and located north of the junction of the south branch and the main river. The downstream boundary of the Southern Area is the confluence of the Ashuelot River with the Connecticut River at Hinsdale, New Hampshire.

Five configurations of the model were run. The first three represent the Northern, Central, and Southern Areas individually. In the fourth configuration the areas were combined, and the whole river basin constrained on the control point at Hinsdale. In the fifth configuration the model represented the Lamprey River in eastern New Hampshire (see Figure 1.1).

The water-use patterns in the three areas of the model were quite different. In the Northern Area the water was used primarily for recreation and rural non-farm dwelling. In the Central Area, in addition to the recreation and rural non-farm dwelling, there was considerable agricultural and forest activity, and the largest urban area in the basin, the city of Keene. The Southern Area had recreation, rural non-farm dwelling, some agriculture, and forest activity. The primary distinguishing characteristic of the Southern Area was the existence of industrial plants. These plants were located at separated points along the river and used private water sources for processing. It is the existence of these industrial plants that made the Southern Area the most difficult to model.

2.1 Mathematical Model

The model can be expressed in its most general mathematical formulation as follows:

$$\begin{aligned} \text{Optimize} \quad & Z = C^{KL}X^{L} \\ \text{Subject to} \quad & A^{RL}X^{L} \leqslant B^{RP} \\ & A^{L}X^{L} \lesseqqgtr B^{PL} \\ & YX^{L} = \text{Sum} \\ & X^{L} \geqslant 0 \end{aligned}$$

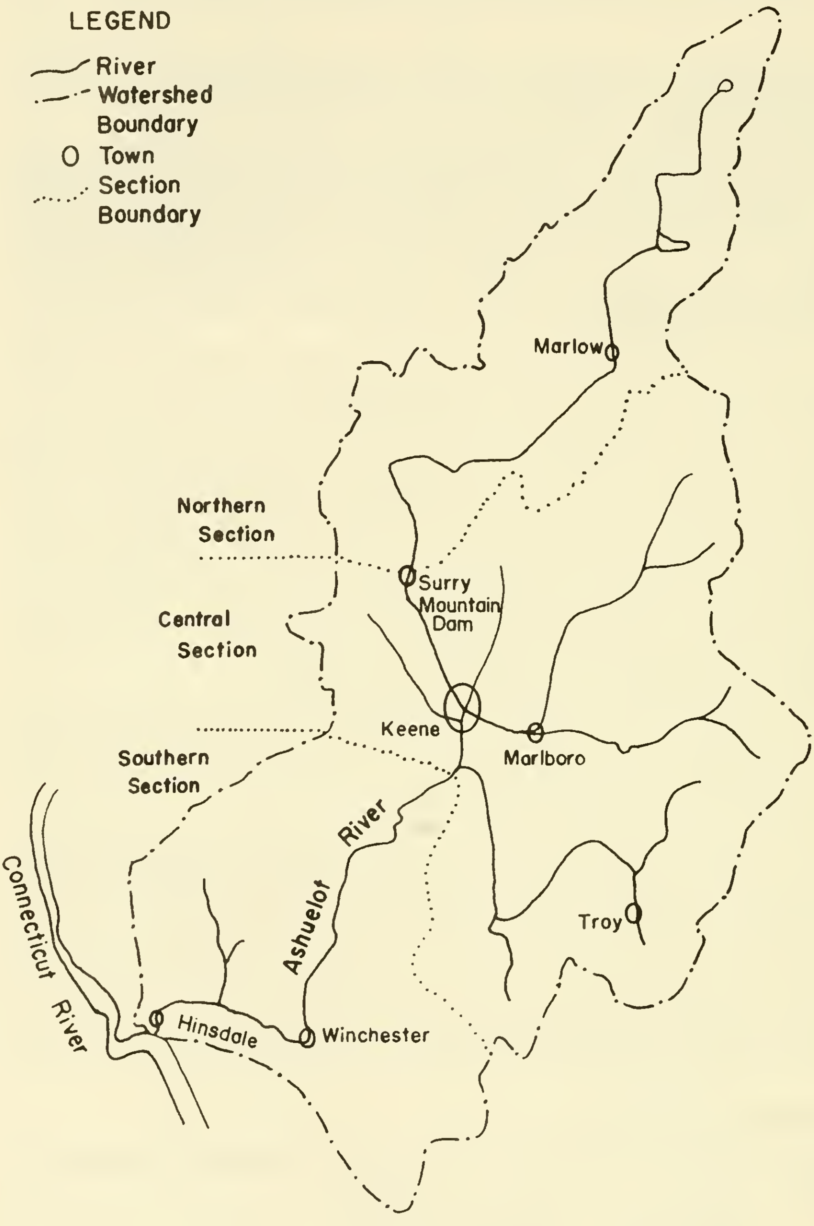


FIGURE 2.1
ASHUELOT RIVER BASIN

Where

C = a 1Xn matrix of cost or return associated with each activity
X = an mX1 matrix of activity levels
A = an mXn matrix of technology coefficients and relations among activities
B = an mX1 matrix of constraint levels
K = identification of costs, returns and quality, set optimized, K=1 to 9 (identifies objective optimized)
L = identification of sector, L = 1 to 7
P = identification of constraint levels (RHS), P = 1 to 27 (4 areas and sub-areas, 3 river-flow levels, 2 river-quality levels, and projection to 1980)
R = river flow, coliform, biochemical oxygen demand, and suspended solids in river
Y = a 7Xn matrix of annual effects including income (value added), recreation day usage, employment, and water use
m varies between areas
n varies between areas

A schematic of the model is shown in Figure 2.2. The model can be visualized in terms of seven independent sectors physically interrelated by the river's flowing through the watershed, with flow and quality constraints imposed on all sectors.

2.2 Flow Levels

In order to recognize the most limiting river-water flow and use situation likely to be encountered, use and flow data for the month of August were utilized. This is a period when the high demands of industrial, domestic, and recreational use are being imposed on relatively low-river flow. As a result the values, quantities, and coefficients in the model are monthly figures, with the exception of impact equations which are on an annual basis. Furthermore, the model was felt to be reasonably representative of areas in southern New Hampshire, and appropriate constraint values or right-hand side values were developed for analysis of the median flow of the Lamprey River. The same A matrix, Y matrix, and C matrix were used in all of the analyses.

Three flow levels were analyzed, one representing dry years, the 10th percentile of 36 years of August flow records; the median flow to approximate normal river flow; and the 90th percentile flow to estimate high-flow years.

Table 2.1 shows a summary of the distribution of 1934-1969 monthly flows of the Ashuelot River with respect to the flow-level assumptions used in the model. For the four months summarized (July through October; 36 years of records), the level of river flow was between low flow (10th percentile) and high flow (90th percentile) for 84 percent of these months. For the months not shown in Table 2.1 (November through June), only six months had less than the August median flow of 2,850.5 million gallons. The river-flow levels for the 432 months in the 36 years of records were between low flow and high flow 50 percent of the time.

The above observations support the conclusion that the flow levels assumed in the model were representative of the conditions in which water quality and quantity would be most limiting on the surface-water-related uses in the basin.

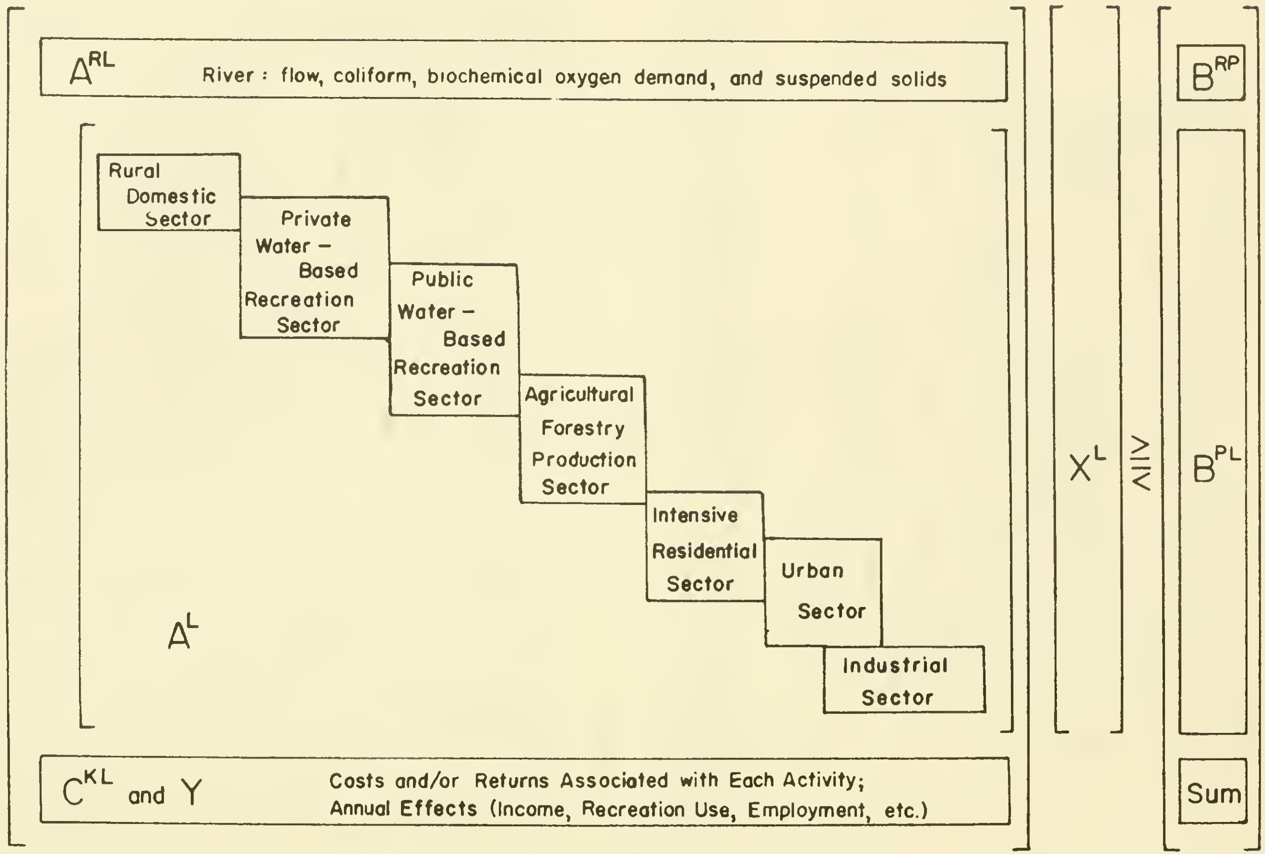


FIGURE 2.2
SCHEMATIC OF ANALYTICAL MODEL USED IN STUDY

Table 2.1 Distribution of Months of July, August, September, and October, Based on August River-Flow level, Ashuelot River, at Hinsdale, New Hampshire, 1934-69.

Flow levels[1]	Month				Total
	July	August	September	October	
	(Number of Months)				
Low flow or less	0	3	1	1	5
Low flow to median flow	12	15	21	13	61
Median flow to high flow	20	15	10	15	60
High flow or more	4	3	4	7	18
Total	36	36	36	36	144

[1] Low flow = 1173.7 million gallons per month (August P_{10})
Median flow = 2850.5 million gallons per month (August P_{50})
High flow = 8610.0 million gallons per month (August P_{90})

2.3 Model Sectors

The seven sectors included rural domestic, private water-based recreation, public water-based recreation, agriculture and forest production, intensive residential areas, urban sector, and an industrial sector. The rural domestic sector represented rural residences in sparsely settled areas where five or more acres per house lot were available. Water use and waste-water disposal were private wells and septic tanks, or dumping into waterways.

The private water-based recreation sector included activities of recreation cottages located on the lake and in tiers back from the lake. The alternative was provided to cottages to have or not to have a motorboat. In addition, private water-based campgrounds and day-use park facilities offered by private firms were included in this sector.

The public water-based recreation sector was similar to the private-based recreation sector. This sector was distinguished by the assumption of public ownership of facilities and the exclusion of vacation cottages.

The agricultural and forestry sector represented primary use of land, with specific ties to river flow and river-water quality. For agriculture, quality of water runoff under three dairy farm practices was included in the model. For forestry, entries involved increased water runoff due to recent cutting, based on timber harvest for the previous two years. Additional flows from the forestry sector from cutting involved not only increases in water flow but changes in water quality.

The intensive residential sector assumed town-type housing with central water supply and with or without community-wide sewerage facilities. Alternatives for securing water included river, ground, and reservoir water through a public system. Waste-water disposal occurred through central processing facilities, individual septic tanks, or dumping waste water directly into the river.

In the urban sector, Keene was considered one unit and included manufacturing, commercial, and residential activities. Industrial demand for water was separate from domestic and commercial demand, but waste water was sent through the same central processing unit. Water was supplied by a central supply and processing unit obtained from ground, reservoir, or river sources. Alternative waste-water-disposal activities included the conventional treatment processes of (1) trickling filter and activated sludge, with the end product discharged directly into the river, and (2) discharging unprocessed waste water into the river.

The industrial sector included three industries found in the lower reaches of the Ashuelot. These were a wool-processing firm, a tannery, and two paper mills. Alternative water sources were permitted, each with numerous alternatives of waste-water processing. Again, one alternative was disposal of waste directly into the river, without being processed.

The overall constraints for all sectors were quality limits imposed on the Ashuelot River itself. Coliform bacteria and biochemical oxygen demand constraints were based upon analysis of the river performed in the summer of 1967 for one set of constraints and for a second set of quality constraints the water-classification level of B-class quality for the entire river.

The objective functions are listed and defined in Appendix B, Table 1. The annual portion of the model is listed and defined in Appendix B, Table 2. The model is quite extensive and in many ways quite complicated. The specific choice of column and row units was dictated by modeling convenience and the terms in which data were available. Also, adjustments in units were made to accommodate the assumptions of linear programming.

The actual model coefficients and control programs are not presented in this report but are available at the cost of computer compilation and duplication.

PART III. INFLUENCE OF CHOICE OF GOALS ON RIVER-BASIN COSTS, BENEFITS, AND RESOURCE ALLOCATION

The identification of goals to be achieved is of prime importance in river-basin resource allocation, as well as identification of costs and benefits. Often these goals are not clear and involve multiple considerations. Nine goals were identified for analysis in this study. These nine goals were then expressed as objective functions to be optimized. The goals were: (1) maximize consumer benefits from water-related recreation use (code name, PRIBEN), (2) maximize water-related production benefits in terms of value added (PRODUCT), (3) maximize gross consumption and production benefits (PRITOT, which equals PRIBEN + PRODUCT), (4) minimize private variable costs of providing potable water and waste-water disposal (PRICOST), (5) minimize public variable costs of providing potable water and waste-water disposal (PUBCOST), (6) minimize combined public and private costs of providing potable water and waste-water disposal (SOCCOST, which equals PRICOST + PUBCOST), (7) maximize net benefits of water-related activities (REVOWAT, which equals PRITOT less SOCCOST), (8) maximize net private benefits (PRINET, which equals PRITOT less PRICOST), (9) maximize environmental quality by minimizing coliform bacteria count and biochemical oxygen demand.

The first six objectives are summarized in the seventh by maximizing net benefits.

The objectives being optimized have an effect upon the costs of providing adequate water supplies and waste-water disposal both in terms of levels and incidence of costs. Further, the objective being optimized has a substantial effect on level of economic activity as measured in terms of direct and indirect income effects to the area, upon level of labor employment, and to all other resource employment in the area. Quantification of these influences is presented in Appendix B, Table 3.

The importance of the *choice of goals*—objective functions in this case—is the critical topic in this discussion. The effect of goal selection on the level of economic activity, incidence of costs, and allocation of resources is described in that order.

3.1 Effect of Objective Function on Level of Economic Activity

The influence of each objective function optimized on the area as measured in terms of direct and indirect annual benefits (VALADT) and on monthly (August) net benefits (REVOWAT) is described in Figure 3.1. Maximizing *net benefits* (REVOWAT) provides a standard for comparison. It not only resulted in the highest net benefits for August but also provided annual benefits that were as high or higher than any objective function optimized.

Maximizing total benefits (PRITOT), *net private benefits* (PRINET), and *production benefits* (PRODUCT) resulted in as much annual benefits as maximizing net benefits but brought about inefficient resource use. Maximizing *consumption benefits* (PRIBEN) but ignoring industry resulted in substantially lower net benefits to the basin.

Minimizing public costs (PUBCOST) or *private cost* (PRICOST) separately or combined (SOCCOST) resulted in lower levels of economic activity. The

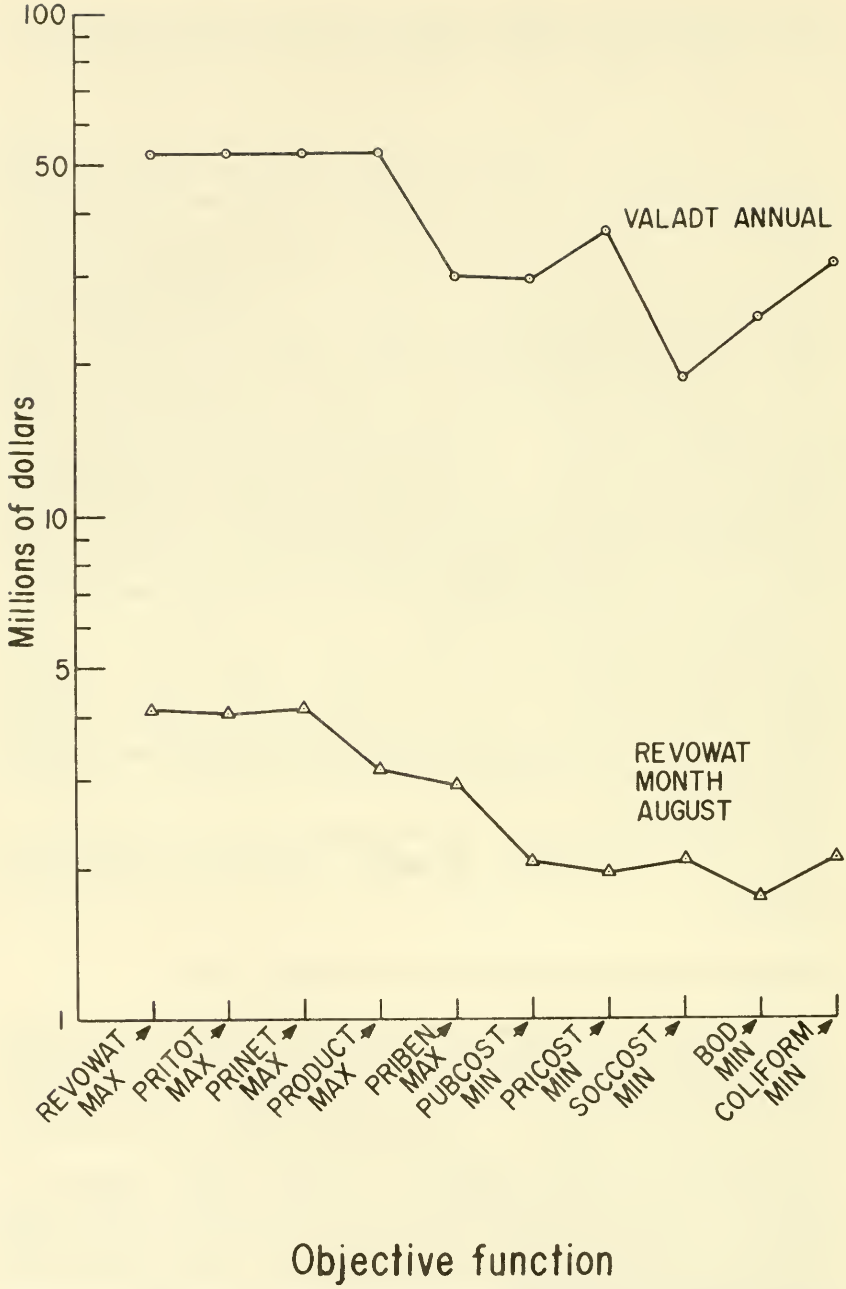


Figure 3.1. Effect of objective optimized on annual direct and indirect benefits (VALADT) and on month of August net benefits (REVOWAT). (Lines connecting points are descriptive and should not be interpreted to represent a continuous function.)

incidence of cost may be allocated more optimally by minimizing public and private cost combined than by minimizing each separately.

Optimizing environmental quality, as measured in terms of minimizing coliform or biochemical oxygen demand (BOD) in the river on a basin-wide basis, also had a retarding effect upon annual benefits and net benefits for the month of August.

3.2 Effect of Objective Function on Cost

The influence of the nine goals optimized on public cost (PUBCOST), private cost (PRICOST), and combined costs (SOCCOST) is portrayed in Figure 3.2. Three major observations are illustrated. First, the figure shows the trade-offs that would be expected between the public and private sectors, depending on objectives optimized. Second, private costs (PRICOST) showed a greater magnitude of variation than public costs (PUBCOST). Third, maximizing environmental quality (BOD MIN and COLIFORM MIN) carried a high cost, which was allocated to the private sector.

Often there develops a controversy between who should bear the cost of providing clean water, the private sector or the public sector. The obvious comparison is minimized public costs (PUBCOST) versus minimized private costs, (PRICOST) of providing adequate water supplies and waste disposal. The expected result is borne out; minimizing public costs would mean shifting the cost burden of providing adequate water supplies and waste-water disposal to the private sector. In the same way, minimizing private costs results in shifting costs from the private sector to the public sector. The implication of these findings is that acceptance of changes in goal selection–such as improved environmental quality–is very difficult to secure because the changes are apt to bring about large variations in individual costs.

3.3 Effect of Objective Function on Resource Allocation

The influence of the objective function optimized on annual water use (ANNH2O), recreational user days (RDAYUSE), and total seasonal and year-round labor employment (LABTOT) is shown in Figure 3.3. Two major items are illustrated. First, annual water use (ANNH2O) and number of jobs (LABTOT) reflect level of economic activity as measured in terms of annual direct and indirect benefits (VALADT) shown in Figure 3.1. The second major item highlights internal dilemmas found in two of the nine goals. Recreation use (RDAYUSE) is at its minimum when private costs (PRICOST) are minimized. The dilemma facing individuals is the trade-off between amenity value of recreation and the goal of minimum cost. In the same way, maximizing environmental quality (BOD MIN and COLIFORM MIN) is accomplished by limiting recreation activity. The dilemma facing individuals is how to optimize environmental quality while enjoying some form of recreation. It was found that examination of these goals in terms of optimizing an objective identifies conflicts found within the goal itself.

3.4 Effect of Objective Function and River Flow on Resource Allocation by Sectors

The above analysis has been based on aggregated variables. The goal chosen also has an impact on sectors taken individually. The objectives most useful for

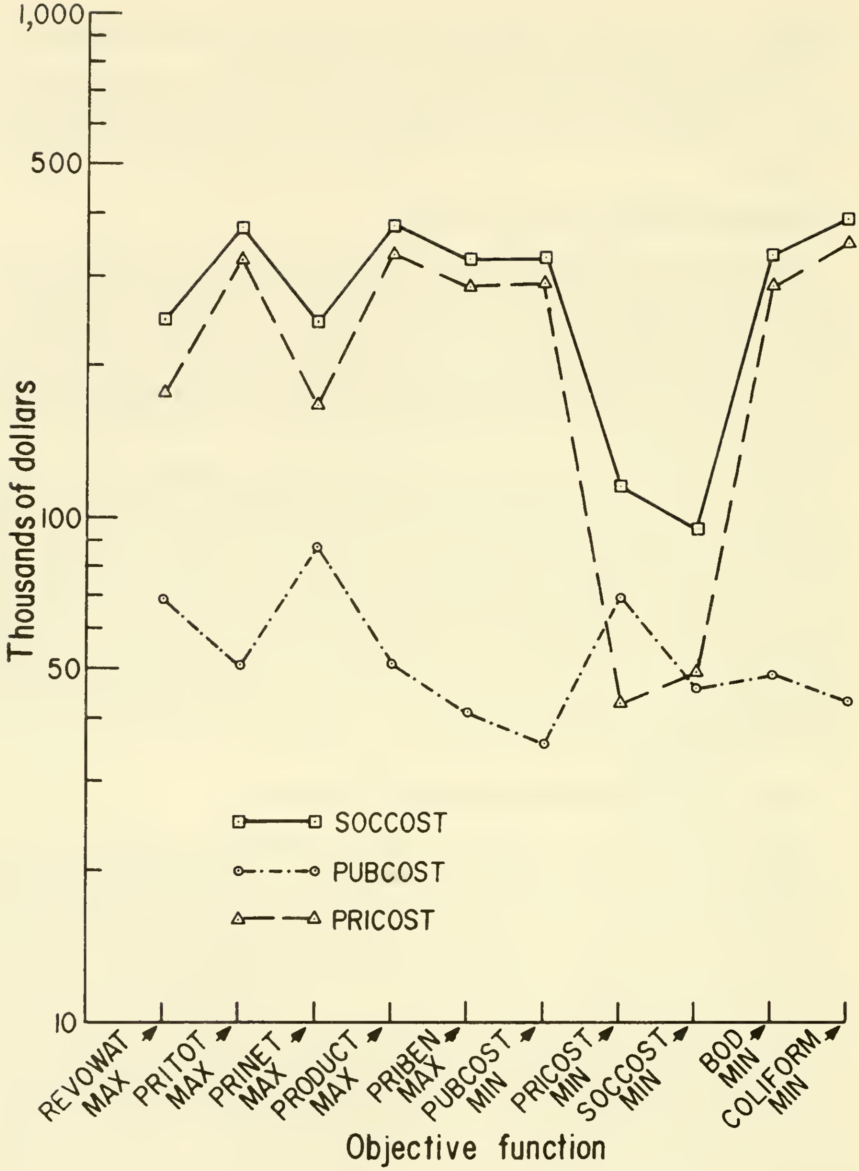


Figure 3.2. Effect of objective optimized on public costs (PUBCOST), private cost (PRICOST), and combined public and private costs (SOCCOST). (Lines connecting points are descriptive and should not be interpreted to represent a continuous function.)

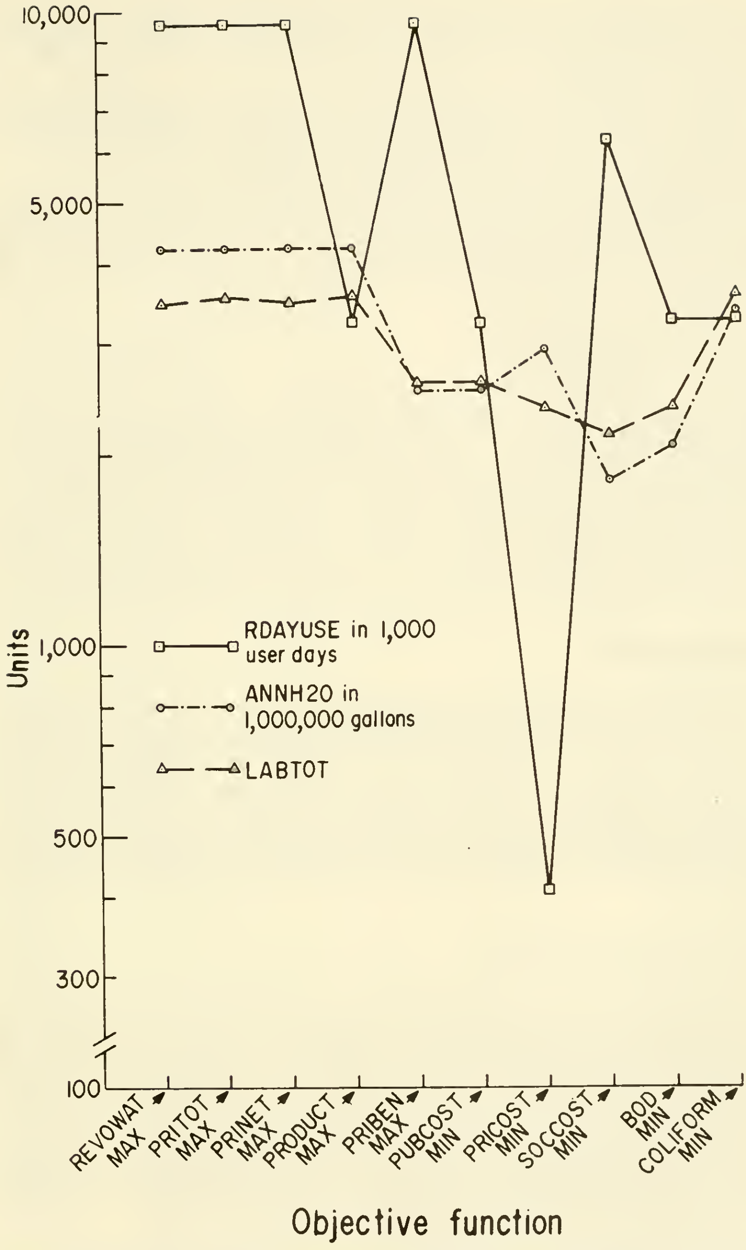


Figure 3.3. Effect of objective optimized on annual water consumption (ANNH2O), number of recreation user days (RDAYUSE) and annual labor employment in man-years (LABTOT). (Lines connecting points are descriptive and should not be interpreted to represent a continuous function.)

evaluating alternative water uses appear to be (1) minimizing public and private costs (SOCCOST), (2) maximizing gross benefits (PRITOT), and (3) maximizing net benefits (REVOWAT).

Other than the lake-oriented recreation sectors, resource allocation is greatly influenced by river-flow level as well as choice of goals. Resource allocation by sector is taken up in detail in ensuing parts of this report. The discussion here is mainly limited to the interaction between goals and flow level.

Selected resource-use quantities for the rural, recreational, forestry, agricultural, intensive residential, urban, and industrial sectors for the objective functions maximizing net benefits (REVOWAT), as well as minimizing public and private costs (SOCCOST) and maximizing gross benefits (PRITOT), are shown in Table 3.1.

3.41 Rural Household Sector

Disposal of waste from private households directly or indirectly into a river or stream without treatment is a low-cost method of waste-water disposal. This practice is not uncommon. It should come as no surprise that for each of the optimized objectives, rural household disposal of untreated waste water was an optimal method of waste disposal at high (and sometimes median) river-flow levels.[1] When minimizing public and private costs, about one-fourth the rural houses were on this method, even at low river-flow levels. *Optimizing in terms of lowest cost* still called for this practice. Maximizing net benefits did not.

3.42 Recreation Sector

As will be discussed later, the recreation sector, mainly based on availability of lake areas, was not influenced by river-flow levels. In contrast with benefit maximizing objectives, when only cost of providing clean water (SOCCOST) was considered, shore-front vacation homes with bigger lots as well as substantially fewer non-shore cottages were shown to be optimal. The cost was also accompanied by less recreational activity in almost all areas of water-based recreation. Minimizing cost became less attractive as an objective in terms of quantity of use.

3.43 Forest and Agriculture Sector

Forestry production remained unaltered by river flow except when minimizing public and private costs of providing water supply and waste-water disposal. In median- and low-flow years, forest cutting practices were curtailed. This revenue-producing activity was curtailed due to flow and water-quality constraints, even though half the rural houses were allowed to dispose of household waste water directly into the river. For all objective functions, the number of farms was reduced and production practices were changed in low-flow years. The change occurred at median-flow years for the objective of minimizing public and private costs (SOCCOST).

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[1] High-flow levels were at the 90th percentile level (for August, 90 percent of the years were below this level), and low-flow levels were at the 10th percentile. See Part II for description of flow levels.

Table 3.1. Selected Land and Water-Resource Uses for Three River-Flow Levels, Three Objective Functions and River-Water Quality of B Class Above and C Class Below Surry Mountain Dam, Ashuelot River Basin

Activity Description	Net benefits			Public and private costs			Gross benefits		
	River-flow level			River-flow level			River-flow level		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
				Level of activity					
Recreation and rural household sector									
One rural household, 4 people	2,936	2,936	2,936	2,936	2,936	2,936	3,586	3,586	3,586
a. Waste-water discharge, no treatment	2,936	2,409	0	2,936	2,936	843	3,586		
b. Waste-water discharge, septic tank	0	527	2,936	0	0	2,093	0	3,586	3,586
One shore cottage									
50' x 400' lot with boat	316	316	316				316	316	316
50' x 400' lot without boat	115	115	115				115	115	115
100' x 200' lot with boat		0							
100' x 200' lot without boat		0							
100' x 400' lot with boat		0		189	189	189		0	
100' x 400' lot without boat		0		242	242	242		0	
One non-shore cottage with boat	0	0	0	91	91	91	0	0	
One non-shore cottage without boat	5,805	5,805	5,805	151	151	151	5,805	5,805	5,805
Private tenting, tent sites water access	160	160	160	160	160	160	160	160	160
Private tenting, tent sites no lake access	248	248	248	248	124	124	248	248	248
Public beach facility, 4 people unit	24,623	24,623	24,623	22,468	22,468	22,209	24,623	24,623	24,623
Public boat launching, 4 people	148	148	148	148	148	148	148	148	148

(Continued on next page)

Table 3.1 (Continued)

Activity Description	Net benefits			Public and private costs			Gross benefits		
	River-flow level			River-flow level			River-flow level		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
				Level of activity					
One swimmer-month	113,200	113,200	113,200	93,245	93,245	92,206	113,200	113,200	113,200
Public park, day use, 4 people	25	25	25	20	20	20	25	25	25
Public tenting, 9.2 tent sites	2.2	2.2	2.2	1.1	1.1	1.1	2.2	2.2	2.2
Forest and agricultural sector									
1. Last year cut, acres	2,650	2,650	2,650	2,650	850	850	2,650	2,650	2,650
2. Next to last year cut, acres	2,850	2,850	2,850	2,850	450	450	2,850	2,850	2,850
One dairy farm, usual practice	22	22		22			22	22	
One dairy farm, some waste management									
One dairy farm, extensive waste management			12		12	12			12
Intensive residential sector									
One household, 4 people	1,488	1,488	1,488	1,488	1,488	1,488	1,488	1,488	1,488
River source of water supply, MG	0	0	10.8	0	0	0	0		11.5
Ground source of water supply, MG	11.8	11.8	1.0	11.8	11.8	11.8	11.8	11.8	1.0
Waste water treatment public, 90% effective	0	1,488		0	0	1,488	0	0	0
Private septic tank, 100% effective	0	0	1,488	0	0	0	0	0	1,588
Waste water, no treatment	1,488	0	0	1,488	1,488	0	1,488	1,488	0
Urban sector									
River source of water supply	3.8	3.8	53.8	3.8	3.8	3.8	53.8	53.8	53.9
Lake source of water supply	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Ground source of water supply	50	50	0	50	50	50	0	0	0

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Table 3.1 (Continued)

Activity Description	Net benefits			Public and private costs			Gross benefits		
	River-flow level			River-flow level			River-flow level		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
					Level of activity				
Urban sector (continued)									
Waste water treatment, 90% effective		99,657	99,657			99,657	99,657	99,657	99,657
Waste water treatment, 80% effective	99,657	0	0	99,657	99,657	0	0	0	0
Industrial sector									
Paper products, new technique, one ton	2,090	2,090	2,090	922.5	0	1,062	2,090	2,090	2,090
Paper products, present technique, one ton									
Paper products, old technique, one ton				68.3	508	2.0			
1 Waste-water treatment, private, percent of waste-water treatment by this method	100						96		
2 Waste-water treatment, public 90% effective, percent of waste-water treatment by this method		100	100			100		78	100
3 Waste-water treatment, private, percent of waste-water treatment by this method				100	5				
1 Waste-water treatment, private, percent of waste-water treatment by this method					95				
BOD transferred to river lbs. BOD	139,480	18,660	18,660	83,620	16,970	9,560	141,500	45,600	18,660
Wool production, new technique, 1,000 lbs.	691,600	691,600	691,600	691,600	386,200	386,200	691,600	691,600	691,600
Wool production, present technique, 1,000 lbs.									
Wool production, old technique, 1,000 lbs.									
BOD transferred to river lbs. BOD	36,314	4,555	4,555	36,305	8,416	3,000	13,202	22,198	3,676

(Continued on next page)

Table 3.1 (Continued)

Activity Description	Net benefits			Public and private costs			Gross benefits		
	River-flow level			River-flow level			River-flow level		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
				Level of activity					
[2] Public treatment waste water, percent of waste		100	100			100			
Tanning production, new technique, one hide	96,017	96,017	90,389	7,535	3,900	26,556	96,017	96,017	94,556
Tanning production, old technique, one hide				19,738	23,027				
BOD transferred to river lbs. BOD	57,094	57,508	19,886	27,433	21,244	14,605	21,124	21,124	21,124
[2] Waste-water treatment, (public) lbs. BOD	7,378	1,462	0		23,027	0	0	0	0
Objective functions, month of August									
REVOWAT in $1,000	4,175	4,161	4,080	3,038	2,028	2,288	--	--	--
SOCCOST in $1,000	234.7	247.	302.	89.9	94.6	119.8	--	--	--
PRITOT in $1,000	4,409	4,408	4,381	3,127	2,123	2,407	4,409	4,409	4,392
Annual impact in 1,000,000	52.3	52.2	51.7	37.4	18.5	24.4	52.3	52.3	51.9

Waste-water treatment

[1] Sedimentation primary, irrigation secondary

[2] 90% effective, activated sludge

[3] Sedimentation primary, activated sludge secondary

Maximize net benefits = REVOWAT

Maximize gross benefits = PRITOT

Minimize public and private cost = SOCCOST

3.44 Intensive Residential and Urban Sectors

Interactions between objective function and river flow substantially influenced water procurement and waste-water treatment called for by the solutions obtained.

High flow: Resource allocation was the same when net benefits (REVOWAT) were maximized and public and private costs (SOCCOST) minimized. When gross benefits (PRITOT) were maximized, urban water procurement and waste water-treatment differed from their allocations under the other two objectives optimized.

Median flow: For the urban sector, either water procurement source or waste-water treatment process differed among objectives optimized. In the intensive residential area, maximized net benefits (REVOWAT) resulted in a waste-water treatment process different from the other two objectives.

Low flow: Only one similarity in resource allocation was found among the three objectives optimized. This was waste-water treatment in urban sector.

For maximized net benefits (REVOWAT) and gross benefits (PRITOT), intensive residential and urban water supply sources were taken from the river instead of from the less expensive ground sources. The reason for this was that removal and use of river water along with subsequent treatment of waste water was a low-cost method of improving river-water quality.

3.45 Industrial Sector

The double influence of goal-optimized and river-flow level was greatest in the industrial sector. At all river-flow levels the results of minimizing public and private cost (SOCCOST) were substantially different from the results obtained from the other two goals optimized. The level of industrial output was lower, with one exception, and old technology was used in the paper and tanning industries. When net benefits (REVOWAT) were maximized, production and technology used in the three industries were about the same as when gross benefits (PRITOT) were maximized. In these solutions production was unaffected by river flow, except in the tanning industry in low-flow years. One similarity among the three goals was identified. With only one exception, the solutions called for public waste-water treatment at one or more of the river-flow levels. This indicates an economic reason for coordinating effort between community and industry in waste-water treatment.

High-river flow: Wool production at high-river flow was the same for the three goals optimized. Aside from similarities mentioned above, no other results were the same.

Median-river flow: Public treatment of waste water from the paper industry was common to results for maximized net benefits (REVOWAT) and for maximized gross benefits (PRITOT). Public treatment of waste water from the tanning industry was common to results for maximizing net benefits (REVOWAT) and minimizing public and private costs (SOCCOST).

Low-river flow: Public treatment of waste water from the paper industry was common to all three goals. BOD transferred from the paper industry to the river was the same for maximizing net benefits (REVOWAT) and for maximizing gross benefits (PRITOT).

3.5 Summary

The existence of material differences in economic activity as well as in resource and cost allocation have been demonstrated as a result of the objective optimized. The incidence of bearing the cost of providing water supply and waste-water disposal shifts with the objective emphasized. For individual sectors, river-flow level also influences resource allocation and incidence of costs. Proponents of some specific objective can often find economic support for their positions although the position may not be in the "general interest." In a river basin that includes many activities, conflicts over resource use and cost allocations arise. They can be resolved in a basin-wide approach which considers all costs and benefits. Resolving conflicts can be further facilitated by identifying a common goal and a river-flow level around which decision-making can take place. The goals which include most economic activity are maximizing net benefits (REVOWAT) and minimizing public and private costs (SOCCOST).

PART IV. LAKE-WATER RESOURCES

Most lakes in the Ashuelot River Basin as well as in all of southern New Hampshire are hydrologically separated from rivers by dams. A few lakes were created entirely by the strategic placement of one or more dams. Recreation lakes are under an administrative structure that regulates the dam gates to maintain the height of the lake for recreational purposes. The Surry Mountain Dam was constructed for flood prevention purposes. It is now a multi-purpose dam providing both flood prevention and a small lake for recreation. Aside from the Surry Mountain Dam, most recreation lakes are located in the headwaters of the Ashuelot River or one of its tributaries draining into the Ashuelot River.

In dry years very little water passes over or through the dam structure on recreation lakes. In years of high rainfall, overflow is observable. The height of the recreation lake is maintained, within limits, in both cases. The surplus overflow is reflected in river flow for the month. The recreation lake is almost independent of river-flow level.

Dams used to create reservoirs for water supply and for flood control are discussed elsewhere in this report. Many dams were built for some now defunct reason and now provide only wildlife habitats.

4.1 Lake Resources in the Ashuelot River Basin

Lakes of more than ten acres in the river basin contained 3,020 water-surface acres, with 363,000 feet of shoreline. Along the shore, a 1,000-foot strip of land provided some 8,340 acres for recreational and/or conservation uses, either public or private. In the northern reaches of the basin, Pillsbury State Park and Surry Mountain Park occupied some 4,400 acres of recreational area and 78,000 feet of lake shore. Public park resources were identified separately from private resources.

From adjusted actual counts of recreation cottages, there were 431 shore cottages and 242 non-shore cottages required in the analysis to reflect current resource use. The model permitted choices of six different boat- and lot-size cottage combinations for shore properties, and two non-shore combinations. A minimum of 215, 40-horsepower equivalent outboard motorboats was also required in the analysis. Similarly, a minimum of private and public camping sites was required to reflect the current situation for tenting with access to water and tenting without access to water. Beach and boat launching facilities were available, and the size of automobile parking facilities provided a basis for estimating minimum use.

4.2 Results: Lake and Related Land-Resource Use

Those who during the day used beach and non-shore vacation cottages without access to water were large users of lake resources and, to a large extent, set the economic base for lake-oriented land and water-resource use. Both were in the programmed results by about a multiple of 20 of current levels. A practical meaning can be attached to this high level of use because it substitutes for discounting future returns for holding the shoreline and recreation area resources at near present levels and describes potential future development.

With existing price ratios, shore cottages and non-shore cottages with access to water were held to present levels. Shore cottages which were optimal for resource use were those with smaller lot sizes and shortest shorelines. Private non-shore tenting increased to maximum levels of resource use, while tenting facilities with access to water were held at present levels. Public park facilities for tenting use increased beyond present levels.

Boating, in terms of 40-horsepower equivalent, was available to shore cottage owners, non-shore cottage owners, tenting with access to water, public park users, and private launching sites. Based on a recommendation by a Michigan study, 10 acres of water surface were required by each boat while in use.[1] Boats launched at private launching sites entered the basin at minimum levels. In total, programmed boat use exceeded minimum usage by about one and one-half times.

4.3 Results: Implied Prices for Lake Surface, Shoreline, and Recreation Area

The lake surface (through water-level management), shoreline, and the recreation area are each fixed. In the linear programming algorithm, fixed resources, which are fully utilized, receive a shadow price. This shadow or implied price evaluates one unit of the activity, an acre of lake surface for example, at the level of utilization obtained in the analysis. The shadow prices for the month of August were obtained and extended to a three-month season by simple multiplication. A capitalized value was obtained by discounting the seasonal value into perpetuity at three percentage rates of return. The shadow prices discussed in this section where obtained by optimizing net benefits.

In the northern area, the shadow or implied price for lake surface was $1.40 per acre for August. The corresponding value for the central and southern areas was $2.45 (see Table 4.1). Because implied prices are primarily derived from foregone opportunities, these estimates would not be expected to include scenic splendor nor certain amenities. Expanding these data from a one-month base to three-month season and then discounting at 5, 7, and 10 percent, estimated surface-water value ranged from $42 per acre to $147 per acre. Where 7 percent was used as the customary interest rate for individuals, values at this discount rate tended to more closely approximate current values and to be consistent with the assumption of the model. These values were $60 for the northern area and $105 for the rest of the basin.

For shoreline length measured in linear feet, market prices for comparison are available. Actual asking prices for choice lots on lakes providing the range of water activities are $100 per foot and greater. The implicit programmed price of $252 per foot, as indicated at the 5 percent discount level, does appear to have been reached for intensively developed properties. Of course the price of shoreline would vary with accessibility and quality of beach involved in the shoreline. It is interesting to note that the model did reflect approximate market prices and indicates a tendency toward even higher prices for shoreline.

The item called "conservation reserve" was land set aside from development by the model in a ratio of 20:1—one unit or recreation area was set aside in conservation reserve for each 20 units used by the private sector. This land would remain undeveloped. The unit is one foot of shoreline by 1,000 feet

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[1] Michigan Department of Conservation. *Michigan Outdoor Recreation Plan*. Lansing, Michigan: Michigan Department of Conservation, 1967.

Table 4.1. Value of Lake Surface, Shoreline, and Conservation Preservation of Land and Shoreline, Based on Maximizing Net Benefits, Ashuelot River Basin

Item	Lake surface (per acre)		Shoreline (linear foot)		Conservation Reserve one foot shoreline by 1,000 feet deep	
	Northern area	Basin and other areas	Northern area	Basin and other areas	Northern area	Basin and other areas
			Dollars			
Value as indicated by shadow price:						
for August	1.40	2.45	4.20	4.20	5.75	5.75
For three-month season:	4.20	7.35	12.60	12.60	17.25	17.25
Discounted into perpetuity						
At 5 percent	85.00	147.00	252.00	252.00	345.00	345.00[1]
At 7 percent	60.00	105.00	180.00	180.00	246.00	246.00[1]
At 10 percent	42.00	73.00	126.00	126.00	172.00	172.00[1]

[1] Acre value of conservation reserve land in rounded numbers:

	Per-acre value in dollars
At 5%	15,000
At 7%	10,600
At 10%	7,500

Maximized net benefits = REVOWAT

deep, the legally defined depth of the recreation area surrounding a lake. The implied price for conservation reserve can be viewed two ways: (1) the cost of maintaining undeveloped area around a lake in terms of price per acre and (2) the cost of lakeshore land in price per acre. A per-acre value was developed and is found in footnote 1 of Table 4.1. Although the prime factor in value of lots is length of shore frontage, the per-acre value at the 5-percent and 7-percent level of $15,000 and $10,000 tends to approximate the per-acre value of lots currently being sold on medium-size lakes. The $15,000 figure represents a sizable penalty for private land-owners for holding such land.

In comparing the implicit prices of shoreline taken separately and shoreline with a lot 1,000 feet deep, we found that in general three-fourths of the value was attributable to the shoreline alone.

The above analysis is based upon optimizing net benefits (gross benefits less public and private costs of providing potable water, and providing for waste-water disposal). The same information was determined for maximizing gross benefits. The results are presented in Table 4.2. No differences between net

Table 4.2. Value of Lake Surface, Shoreline, and Conservation Preservation of Land, Based on Maximizing Gross Benefits, Ashuelot River Basin

Item	Lake surface (per acre)		Shoreline (linear foot)		Conservation Reserve one foot shoreline by 1,000 feet deep	
	Northern area	Basin and other areas	Northern area	Basin and other areas	Northern area	Basin and other areas
	Dollars					
Value as indicated by shadow price:						
for August	1.40[1]	2.45[1]	4.20[1]	4.20[1]	6.05	6.05
For three-month season	4.20	7.35	12.60	12.60	18.15	18.15
Discounted into perpetuity:						
At 5 percent	85.00	147.00	252.00	252.00	363.00[2]	363.00[2]
At 7 percent	60.00	105.00	180.00	180.00	259.00[2]	259.00[2]
At 10 percent	42.00	73.00	126.00	126.00	181.00[2]	181.00[2]

[1] Same as REVOWAT

[2] Acre value in rounded numbers:

	Per-acre value in dollars
At 5%	15,800
At 7%	11,300
At 10%	7,900

benefits and gross benefits were found for lake surface and shoreline length. However, for the conservation reserve, the monthly value increased from $5.75 to $6.05 per unit.

4.4 Implicit Values for Lake Shore Cottages

Vacation homes or cottages currently located on lakes were not good competitors with other recreational uses of lake resources. Actual prices ranged from $10,800 to $19,000 depending on size of lot, length of shore frontage, and boat use (see Table 4.3). The cottage with 50 feet of shoreline and one-half acre of land was the only type in optimal allocation, and then only at current or minimum levels. When gross benefits (PRITOT) were maximized, the shadow price was positive at $149 for the northern area and $154 for the other areas and the basin. This indicated that the requirement of having cottages in the analysis resulted in a net loss of $149 for the marginal unit in the northern area. Further analysis indicated that no cottages would be found on lakes if this minimum

Table 4.3. **Implied Prices and Market Prices of Vacation Cottages With Shore Frontage Based on Maximized Gross Benefits, Ashuelot River Basin**

Shore cottage identification[1]	Price in Model	Dual Variable: Northern area	Dual Variable: Basin and other areas	Lowest price at which cottage enter basis: Northern area	Lowest price at which cottage enter basis: Basin and other areas
		Dollars			
		Month of August			
Cottage (minimum requirement)	0.0	149	154		
B Cottage 1 (50' x 400')	123.	–	–	–	–
Cottage 2 (50' x 400')	110.	–	–	116.	–
B Cottage 3 (100' x 200')	174.	–	–	348.	348.
Cottage 4 (100' x 200')	156.	–	–	341.	336.
B Cottage 5 (100' x 400')	194.	–	–	388.	388.
Cottage 6 (100' x 400')	175.	–	–	381.	376.
		Total Capital Value			
B Cottage 1 (50' x 400')	12,000.	–	–	20,100.[2,3]	20,500.[2,3]
Cottage 2 (50' x 400')	10,800.	–	–	19,700.[2]	19,600.[2,3]
B Cottage 3 (100' x 200')	17,000.	–	–	25,700.	25,700.
Cottage 4 (100' x 200')	15,300.	–	–	25,300.	24,900.
B Cottage 5 (100' x 400')	19,000.	–	–	28,800.	28,800.
Cottage 6 (100' x 400')	17,000.	–	–	28,000.	27,600.

[1] B identifies cottage with boat.
[2] Cottage price (Cj) or shadow price plus dual variable on Cottage (Min.)
[3] Minimum price required before the number of vacation cottages B Cottage 1 and Cottage 2 would increase above minimum found in the area. For other vacation cottages to increase above the minimum in the area, the prices must be raised to the equivalent of the lower price at which the cottage would enter the basis plus the value of the dual variable on Cottage (minimum requirement).

Maximized gross benefits = PR1TOT

requirement were removed. To develop a price at which shore cottages would appear in the results at levels above the required amount, the shadow or implied price was added to the model price. For a cottage on a small lot and with a 40-horsepower boat equivalent (B cottage 1),[1] this was the model price of

[1] The "B" preceding the word "cottage" indicates a vacation cottage with boat powered by a 40-horsepower outboard motor. Other cottages are assumed not to have this equivalent in boat equipment.

$123 plus the shore cottage shadow price of $154 for the basin. The value of a cottage located on 50-foot shore length frontage, one-half acre in size, and with a boat, would have to be raised from $12,000 to $20,500 before expansion in this size of cottage would occur. For the same cottage but without boat (cottage 2), the price would have to be raised from $10,800 to $19,600.

For the other vacation cottages included as alternatives, the price at which they would enter the solution was calculated. The implied prices as the result of economic forces at work in the linear programming model covering a variety of water and related land recreational uses were substantially above those used in the model as original prices. B cottage 3 and cottage 4 differ from B cottage 1 and cottage 2 by having an additional 50 feet of shoreline, with lot size maintained at one-half acre. The data in Table 4.3 indicate that 50 more feet of shoreline are worth in the neighborhood of $5,000 or $100 a running foot. The differences between B cottage 3 and cottage 4 with B cottage 5 and cottage 6 represent differences in acreage with shoreline held constant. The added half-acre was worth about $3,000 or about $6,000 per acre.

4.5 Effect of Raising Vacation Cottage Price

The monthly price for B cottage 5 was increased from $195 to $390 and for cottage 6 from $175 to $385. These levels of increases were necessary to obtain changes in the basis and reflected changes in shadow prices. The higher priced lot for B cottage 5 and cottage 6 only served to replace B cottage 1 and cottage 2 in the analysis. Number of cottages remained the same, and the shadow price for one vacation cottage declined from $154 to $146 for the basin. In order for expansion to occur in cottages typical of B cottage 5 and cottage 6, the $380 or so would have to be raised by about one-third. This would increase the price of one-acre lots with 100 feet of shore front with cottage to a price range of $35,000.

Based on real estate advertisements in newspapers and local magazines, the implicit prices found in the model for shoreline lengths, conservation reserve, and cottages of different sizes and location appeared to be reasonable approximations of current prices toward which the 1970-72 price situation was tending.

The influence of raising the price of B cottage 5 and cottage 6 on other shadow prices varied. The shadow price for conservation reserve and shoreline length changed very little. On the other hand, the lake-surface shadow price (basin-wide) declined from $2.45 to $1.00 and was the only major item that experienced a large relative damage. The large lot sizes reduce demands on lake resources and lake surface. In resource reallocation, day use of beach facilities was most affected by a decline in number of users. Boating use remained unchanged.

The increased lot size and accompanying increased shoreline length could be a major planning tool for regulating water use. By requiring large lot size, less demands would be placed upon the lake-surface water; this usage would contrast with the current trend for shorter shoreline lengths of about 50 feet, as under standard market and recreational resort development practices.

4.6 Public and Private Park Tenting and Day Use

In the model, public park land and shoreline were removed from total recreation resource and included as individual activities.

Within the park, shadow prices for tenting and day use of park facilities were less than the net prices employed in the analysis. This indicates that more facilities should have a beneficial effect but that benefits from additional units are declining. Park land and shoreline were valued at the same shadow price as private resource holdings.

Private tenting with access to water was dominated by other shore front activities, received a positive shadow price, and did not expand beyond the minimum now available. In contrast, private tenting without access to water expanded to its constraint maximum (double present facilities), with a shadow price equal to its model price.

4.7 Boating and Pollution from Outboard Engine Exhaust

The major determinant of the imputed value of lake surfaces was boating. Guidelines for boating use have been provided by the *Michigan Outdoor Recreation Plan* and were employed in determining boat usage.[1] Boats were normalized at 16-foot length with a 40-horsepower outboard engine. Five acres of surface water were assumed, based on intensive usage, and the boat assumed to be under full power one-half of the time.

Residents of vacation homes and tenters were assumed to use their boats two hours per day and the boats to be under full power half of that time, or one hour per day. For day boat users launching at a public or private ramp, the use time was doubled.

In the preceding analysis, 516 boat-months (1 hour per day for 30 days) were used on the 3,020 acres of lakes. This amounted to one boat per 5.85 acres.

The effect of outboard engine exhaust on lake-water quality became a major concern in the analysis. There appears to be a need for much work to be done on this type of pollution under field conditions. Most studies including the most recent begin extending experimental work to field conditions with some assumption about length of operating time and experiment results.[2] The polluting effect of one hour of boating per day, on a monthly average, is unknown.

Parametric programming was employed to investigate effects of pollution on optimum boat use. It was assumed that a water-purifying substance, such as activated carbon, could be employed per hour of boat use at some cost. This boat pollution treatment cost was increased from 0 to $60. The critical value determined was $12.30. At this point the 516 boats declined to 215, the minimum number of boats permitted in the constraints. The number of shore vacation cottages with boats declined by an equivalent amount. The shadow price on surface water declined steadily as pollution abatement cost increased and reached 0 dollars at the critical cost of $12.30 per boat. The large shift in boat numbers at the critical cost was due to the nature of the linear programming model. The large shift is not unreasonable for field conditions because lakes are often zoned to allow no outboard motors.

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[1] *Ibid.*

[2] Environmental Protection Agency. *Control of Pollution from Outboard Engine Exhaust: A Reconnaissance Study.* Environmental Protection Agency, Research and Monitoring, 15020, ENN, September, 1971.

4.8 Sensitivity to Price Change

The resource allocation was stable over a large range of price variability. This may be due to the fact that different recreation activities are not close substitutes. The item most sensitive to price change was low-priced shore cottages. Shore cottages and non-shore cottages, both with and without boats, were close substitutes.

4.9 Summary

Most lakes were used primarily for recreation. Shoreline was dominant in lake surface and recreation area in terms of valuation. Implied prices were as high as $15,000 per acre of recreation land, with shore frontage implied. The principal determinant of lake-surface value was boating; of shore frontage, swimming and day-use facilities; and of recreation area without shore frontage, non-shore vacation cottage use. Resource allocation was quite stable and varied little with small changes in prices. Economic pressures encourage full usage of lake and recreation land resources, with beach activity and vacation cottages on small lots dominating. For most lakes, adequate provision for holding land for conservation purposes are not now effective.

PART V. RESOURCE ALLOCATION, IMPLIED PRICES, AND COST FOR RIVER-CONNECTED ACTIVITIES

Most sectors are directly connected hydrologically and physically by the quality and quantity of river flows. The connection is one way and flows with the river. Linkage with lakes usually is restricted to surplus surface runoff above that required to maintain lake depths by dams. In an economic sense, the interrelations can be reflected in a reciprocal manner throughout the hydrological systems through planning and coordinating activities. Trade-offs among the seven sectors under consideration, low river-flow augmentation, and water supply source can be included.

5.1 Comparison of Present with Potential Resource Allocation

There are two situations of particular interest with respect to resource, cost, and benefit allocation. The first of these is the entire basin for median river-flow levels, class-C quality when public and private costs (SOCCOST) are minimized. This situation is of particular interest because it closely approximates 1967-70 conditions in the basin. These conditions were developed from Census of Manufacturers, Population Census, a survey of industrial water use conducted by the New Hampshire State Planning Office (then of the Department of Resources and Economic Development) and updated U. S. Geological Survey and highway maps. The programmed solution depicts the minimum cost of providing water supply and waste-water treatment under current (1967-70) conditions. The optimal solution for the above minimum cost objective indicated that the following categories of resource use were prescribed at levels similar to current conditions: number of shore and non-shore vacation cottages (with and without boats), public beach facilities, launching facilities, number of farms, the amount of forest harvest, intensive residential and urban water use, the amount of manufacturing activity in the southern Ashuelot area. Mixed production technologies entered the solution, which is more descriptive of the present industry situation than all new or all old technology.

A second part of this particular situation is the same optimization for low-flow conditions, all other characteristics remaining the same. Of particular interest was the shift from mixed technologies in paper production to newer technologies which were less polluting. The results were an increase in gross benefit to the area. The change in technology and resulting increase in gross benefit was not by design of the model but because the newer technology was less polluting. The shadow price on biochemical oxygen demand (BOD) is an indication of marginal cost to the basin of meeting current river quality under approximate current levels of economic activity. For median river-flow level, the marginal cost was \$0.109 per pound of BOD removed; for low-river flow, it was \$0.56 per pound; and for median-flow, but B-class, \$0.12 per pound.

When public and private costs are minimized, benefits move in a variety of directions without the guidance of income incentives. This leads to a second situation of particular interest, maximizing net benefits (REVOWAT).

Maximizing net benefits (REVOWAT) resulted in resource allocation and production under profit incentive. Resources were free to move and were constrained by model assumptions and institutional arrangements such as zoning.

Resource allocation for the two situations is described in Table 5.1. Higher levels of economic activity, more industrial, farm and forest production, and more recreation activity occurred when net benefits were maximized than when public and private cost was minimized. The economic activity expanded to about the maximum under presently known technology. Such expansion is particularly evident, under median- and low-flow conditions, in shadow price per pound of BOD. Under median-flow conditions and current status of the river classification, the C-level of quality was reached at a marginal cost of about 56 cents per pound of BOD treated and increased to $7.08 per pound of BOD under low river-flow conditions. The low flow pretty much reflects the maximum level of development from the basin-wide point of view and optimization under perfect competition. The $7.08 per pound of BOD removed starts to become prohibitive. At median flow and with B-class quality, the cost per pound of BOD was $4.15.

These situations are the bounds for analyzing resource, cost, and benefit allocations.

5.2 Discharge of Raw Sewage is Economic Optimal

The discharge of raw sewage from rural households and small towns into open streams is often economically the best of alternatives open to the household units, communities, and basin. It is less expensive for industry and larger urban areas to treat waste water for meeting quality standards and improving river quality than it is for the smaller units of rural households and small towns.

If the criteria were based solely on public and private cost minimization in the basin, income-generating activity would be reduced to permit rural households to discharge raw sewage into the environment, even under low-flow conditions. The incentive for all rural households to install waste-water treatment facilities (septic tank) occurred only under extreme conditions (low flow, and maximizing net benefits).

Discharge of household waste water directly and indirectly into streams and rivers can frequently be found. There is little social pressure to change this practice. The houses so involved often were built before health restriction preventing this practice became effective. In rural areas, no pressing reason is felt for changing what has been done over time. The practice will survive most blanket measures for improving water quality as stream classification and penalty payments based on damages.

5.3 Influence of River-Flow Level on Resource Use

The river-flow level, reflecting precipitation and runoff rates, had a major influence on optimal waste-water treatment facilities. The effect is complicated and, in analysis, may give rise to what appears to be erratic behavior as flow levels vary from high to low. Small communities appeared to be most involved in change in optimal waste-water treatment. At high river-flow levels, the optimal treatment was no treatment. At the median-flow level, public treatment with the activated sludge process (90 percent effective) became optimal. At low-flow levels, private septic tank treatment (assumed to be 100 percent effective) became optimal. The change at each river-flow level is consistent with change in BOD discharged into the river.

Table 5.1. Resource Use and Production, Selected Objectives Optimized, Median-River Flow, Current Quality of Water, Ashuelot River Basin

Item	Units	Objective Optimized: Public and Private Cost	Objective Optimized: Net Benefits
Recreation sector			
Shore cottage	Number	431	431
Non-shore cottage	Number	242	5,805
Boats, all sources	Number	481	516
Beach use	Number swimmer days	93,245	113,200
Private tenting without access to water	Number sites	124	248
Private tenting with access to water	Number sites	160	160
Publicly owned tenting, access to water	Number sites	10	20
Forest			
Forest harvest			
1. First-year cut	Acres	850	2,650
2. Second-year cut	Acres	450	2,850
Agriculture			
Dairy farm equivalent	Number 64 animal unit equivalent	12	22
Intensive residential			
Water source, ground	Million gallons	11.8	11.8
Waste-water disposal			
Private, no treatment	Number houses	1,488	--
Public treatment, activated sludge	Number houses	--	1,488
Urban (Keene)			
Water source			
River	Million gallons	3.8	3.8
Lake	Million gallons	5.0	5.0
Ground	Million gallons	50.0	50.0
Domestic use	Million gallons	42.8	42.8
Industrial use	Million gallons	16.0	16.0
Waste-water disposal			
Trickling filter	Lbs. BOD treated	99,657	--

Table 5.1. (Continued)

Item	Units	Objective Optimized	
		Public and Private Cost	Net Benefits
Urban (Keene)			
Waste-water disposal (Continued) Activated sludge	Lbs. BOD treated	--	99,657
Industrial sector			
Paper products, old technology	Tons produced	508	0
Paper products, new technology	Tons produced	0	2,090
BOD transferred to river (paper)	Lbs. BOD	16,970	18,660
Wool production, old technology	Lbs.		
Wool production, new technology	Lbs.	386,200	691,600
BOD transferred to river (wool)	Lbs.	8,416	4,555
Tanning production, old technology	1 hide	23,027	0
Tanning production, new technology	1 hide	3,900	96,017
BOD transferred to river	Lbs. BOD	21,244	57,508
Monthly benefits less public and private costs (REVOWAT)	1,000 dollars	2,028	4,161
Monthly public and private costs (SOCCOST)	1,000 dollars	94.6	247.0
Annual gross benefit direct and indirect (VALDAT) to basin	Million dollars	18,543	52,242

As river-flow level decreased, the small communities shifted to waste-water disposal methods which reduced BOD discharged into the river.

This shift is brought out in Table 5.2 for groups of industry. Each industry, and industries as a group, shifted to waste treatments which were increasingly effective in removing BOD as river-flow level decreased. Between groups of industry, the change associated with flow level differed. Major changes in paper and wool industries occurred in moving from high flow to median flow and for tanning in moving from median flow to low flow. The optimal waste-water treatment process in each industry changed, also. In the paper industry, the type of treatment shifted from sedimentation primary, and irrigation secondary at high-flow level to public treatment by activated sludge process at median- and low-flow levels. In the wool industry, the optimal type of waste-water treatment shifted from no treatment at high-flow levels to public treatment with activated sludge at the median- and low-flow levels. In the tanning industry, the optimal treatment shifted from trickling filtration to activated sludge, and production levels were decreased slightly because of the low-flow conditions of the river.

In the urban sector, the appropriate waste-water treatment process shifted from trickling filtration at high-flow levels to activated sludge at the median- and low-flow levels. At low-flow levels, the river was an optimal source of most of the urban water supply because the pre-use and post-treatments of this source of water improved the overall quality of the river. Although this source of water supply may be optimal from a basin standpoint, it is hardly optimal from the urban (Keene) standpoint.

In the rural sector, from a basin-wide standpoint, rural housing shifted from no waste-water treatment to septic-tank treatment, when moving from median- to low-flow river condition. Forestry production was not influenced by river-flow level, but rather contributed to river-flow level through increased runoff due to cutting of timber stands. In the agricultural sector, little change occurred in optimal resource use between high-flow levels and median-flow levels. But when moving from median-flow levels to low-flow levels, the optimal allocation called for fewer dairy farms and for these fewer farms to employ more expensive practices that pollute less.

The influence of river-flow level on resource use was the common tie of waste disposal. Variation in treatment process was a companion to change in river-flow level. Treatment plants involve sizeable capital outlay and are fixed, once built. Shifting between processes and for some firms, entering and leaving production cannot easily be done with each change in river-flow level. In planning, some flow level between the median and low level could serve as a guideline in determining optimal resource allocation under variable flow conditions.

The variation in river flow also leads to differences in cost allocation. Optimal activity on a basin-wide basis may not be optimal for some specific sector. This fact provides economic foundation to conflicts in the choice of activity in water-resource planning among sectors. The conflicts may hinder coordinated effort in reaching quality standards and economic development. However, features in this analysis would encourage cooperative effort. First, the optimal treatment process in industry and in community water purification and waste-water treatment were the same or very similar. Second, there are economies of size in waste-water treatment plants and in cooperative efforts between communities and industry, usually resulting in reduction of cost to all concerned. Third, benefits from coordinated effort may be reciprocal in that the benefits may

Table 5.2. BOD Transfer to River, by Industry Groups for Three Levels of River Flow, Optimal Net Benefit Resource Allocation, Current River Quality (BCC), Ashuelot River Basin

Flow level	Industry Groups			
	Paper	Wool	Tannery	Three-Industry Total
	Pounds			
High (90 percentile)	139,480	36,314	57,094	232,888
Median	18,660	4,555	57,508	80,723
Low (10 percentile)	18,660	4,555	19,886[1]	43,101

[1] Reduction in BOD from median flow is due in part to reduced output.

Maximum net benefits = REVOWAT

differ with different flow conditions. Much in terms of savings in expenditures and opportunity for growth can be achieved in coordinated effort for meeting common goals.

5.4 Influence of River-Flow Level on Benefits and Costs

River-flow level is directly related to assimilative capacity of the receiving water body.

The influence of flow level on the river basin can be aggregated in terms of net benefits (REVOWAT) and public and private costs of providing water used and waste-water treatment (SOCCOST). The influence of river flow on the former is shown in Table 5.3 and the latter in Table 5.4.

Moving from a high-flow level to a median-flow level has a relatively small effect on net benefits or minimum costs.[1] In a marginal sense, and moving from median flow to low flow, net benefits decline by a substantial amount. At the low-flow levels, incremental costs rise rapidly as river flow decreases; at the median-flow levels, cost and net benefits change less as flow level increases. The most useful results would appear to be found at the median- and low-flow levels. It is over this range that net benefits and cost change at the most rapid rate.

5.5 Value of Low-Flow Augmentation

Low-flow augmentation is a means of increasing assimilative capacity. The value of this activity must be weighed against alternatives in achieving specified goals. A crude approximation was developed from the change in net benefits associated with change in river flow and presented in Table 5.5. The estimate is based on variable cost and implies that on the average and for low-flow months, flow augmentation has a value of about five cents per 1,000 gallons. If fixed costs

[1] The optimal solutions at high- and median-flow levels included more waste-water treatment facilities than are now found in the basin.

Table 5.3. Influence of River-Flow Level on Net Benefits, Current Water-Quality Level (BCC), Ashuelot River Basin[1]

Flow level (precipitation)	Net benefits	Change in net benefits
	Dollars	
High (90 percentile)	4,174,745	base
Median	4,160,742	-14,003
Low (10 percentile)	4,079,615	-81,127

[1]REVOWAT maximized at each flow level.

Table 5.4. Influence of River-Flow Level on Public and Private Costs, Current Water-Quality Level (BCC), Ashuelot River Basin[1]

Flow level (precipitation)	Public and private cost	Change in cost
	Dollars	
High (90 percentile)	89,857	base
Median	94,577	+ 4,720
Low (10 percentile)	118,937	+24,360

[1]SOCCOST minimized at each flow level.

Table 5.5. Value of Flow Augmentation, Current River Quality (BCC), Ashuelot River Basin

Flow level	Flow in million gallons per month	Change in flow, million gallons per month	Change in net benefits[1]	Net benefits per million gallons
			Dollars	
High	8,610	base	base	base
Median	2,850.5	5,759.5	-14,003	2.43
Low	1,173.7	1,676.8	-81,127	48.38[2]

[1]From Table 5.3.

[2]About 5 cents per 1,000 gallons.

are five times variable costs, the total value of 1,000 gallons is raised from five to twenty-five cents. These figures may be extrapolated for the number of low-flow months over a period of years when low-flow augmentation may be useful in maintaining water quality. This benefit could be added to other estimated benefits of a dam. A realistic look at the above results, however, indicates that flow augmentation benefits tend to be rather small in view of other alternatives.

Most benefits of flow augmentation would accrue in months of low-river flow. An analysis of Ashuelot River flows for 36 years indicates that months of flow below August low-flow occurred only 1 percent of the time, and months of flow below August median flow occurred only 15 percent of the time.

5.6 Change in Net Marginal Benefits from a Change in Resource Use

The changes in net marginal benefits from a change in resource use are listed in Table 5.6.

In the rural residential sector, the reduction of one house would increase net benefits by $19.75 in low-flow years. Put another way, the addition of one house to the rural sector would add $19.75 in cost to the area. The incremental change in water use in the rural residential sector was associated with $1.11 cost per 1,000 gallons of water supply and $2.23 per 1,000 gallons of waste-water disposal. The cost per 1,000 gallons of water for domestic use in intensive residential areas (towns) and urban (Keene) was somewhat lower, around $0.60 and $0.40 per 1,000 gallons, respectively.

Biochemical oxygen demand (BOD) is a major water-quality constituent and is of particular interest. At high-flow levels, due to dilution factors, there is no cost or benefit associated with a small change in quantity in the river. At median-flow levels, a one-pound change in BOD would change variable costs $0.56 in the same direction. The value would reach $7.08 per pound under low-flow condition but, under low-flow condition, marginal net benefits are somewhat exaggerated. This is emphasized in the agricultural sector where under median and high flow, the contribution is a net marginal contribution to the area economy. In low-flow years, however, the contribution is a detriment due to BOD created by the dairy farm unit.

In the urban sector, water supply source plays an important role in marginal benefits. Groundwater, which needs no treatment, dominates lake supply, which must be treated. The reduction of reservoir supply would result in an expansion of groundwater supply that would add to the net benefit in the basin.

Industrial water use in the urban sector represents a negative influence because value added by the urban industry has a net cost of about $0.65 per 1,000 gallons for median-flow conditions and $1.68 for low-flow conditions.

5.7 Summary

Direct discharge of industrial and household untreated waste water directly into rivers is economically optimal under certain conditions. These conditions include society's tolerance to such activity, large assimilative capacity of the receiving body, and no discharge of toxic materials. Low-flow augmentation to increase assimilative capacity by itself may have low value in terms of alternatives and their cost. Optimal allocation differs with objectives optimized and river-flow level. Perverse behavior of optimal resource use may appear in some sector due to river-flow level, but overall behavior is consistent.

Table 5.6. Change in Net Benefits to Basin Associated With a One-Unit Decrease in Resources Used, Three Flow Levels, Current River Quality (BCC), Ashuelot River Basin[1]

Item	Units	Flow Level		
		High	Median	Low
			Dollars	
Rural, residential				
Rural houses	Household	+11.62	+19.75	+19.75
Rural household water requirement	Million gallons	0	+1,113.70	+1,113.70
Rural household septic tank treatment	Household	0	0	-94.45
Rural household waste-water discharge	Million gallons	0	-2,227.40	-2,227.40
BOD in river	Pounds	0	+0.56	+7.08
Dairy farm	One farm	-1,300. 00	-1,004.20	+1,502.90
Intensive residential				
Community size	No. households	+4.46	+7.15	+12.50
Water requirement	Million gallons	+611.00	+611.00	+599.31
Water-supply treatment	Million gallons	+7.77	+8.95	+42.56
Waste-water discharge	Million gallons	0	+387.55	+1,171.47
Urban				
City size	100 people	+114.93	+138.35	+359.81
Water requirement	Million gallons	+435.08	+429.00	+358.21
Coliform bacteria in urban water supply	Billion organisms	+12.55	+12.55	+12.55
Maximum groundwater supply	Million gallons	-75.08	-69.00	0
Minimum lake-water supply	Million gallons	+5.07	+11.16	+81.93
Water-supply treatment	Million gallons	+21.14	+21.14	+21.14
Waste-water discharge	Million gallons	+107.00	+228.52	+1,391.73
Industrial-water use	Million gallons	+536.72	+646.08	+1,680.36

[1] A negative sign means a decrease and a positive sign an increase in net benefit associate with a reduction by one unit of the amount indicated.

PART VI. INFLUENCE OF OBJECTIVE FUNCTION AND OPTIMIZATION ON THE THREE AREAS IN THE ASHUELOT RIVER BASIN

Many New Hampshire river basins appear to be separable into areas with distinctive flow as well as water- and related land-use characteristics. The Ashuelot River basin was not an exception and was divided into three areas (see Figure 2.1, Part II). The northern area is distinguished by relatively rapid river flow, rural residences, little or no industrial activity, and undeveloped lakes with potential recreation areas. The central area has much slower river flow, more urban area, and a larger agricultural land-use base. The potential recreation areas were more highly developed than in the northern area. The southern area, by contrast, has a generally rapid river flow, with water-dependent industries located in small communities along the river.

All three areas contained a portion of the headwater areas within the basin boundary. Extensive residential and recreation activity was found, but the relative importance of these activities varied with the area. The central and southern areas contained more residential and commercial-industrial development hence the rural and recreation sectors were less important in the total economic activity in these two areas.

6.1 Effect of Goals Optimized in Each Area

The decision-making structure in river basins is largely one of meeting overall legislated standards while each community or sector works with whatever water quantities and quality are available in the adjacent river or lake resources. This is illustrated in the analyses of various objectives optimized for the three separate portions of the river basin. In the analysis each area uses incoming water quantity and quality from the edge of the closest upstream checkpoint. The downstream resource allocation reflects the effects of the resource allocations made by the upstream users.

A comparison of the effects of optimizing five objectives on net benefits, gross benefits, public and private cost, and biochemical oxygen demand (BOD) released into the river, coliform bacteria released into the river, and annual total of both direct and indirect benefits to the area are shown in Appendix B, Table 4.

The effect of choice of objective on the selected items in the northern, central, and southern areas is similar to that found for the basin as a whole. Maximizing benefits, both gross and net, results in greater resource use and total benefits to each area. The difference among the three areas is due to the quantity of resources available and the type of economic activity found in the area.

In the northern area, the difference between the effects of maximizing net benefits and minimizing public and private costs was not as great as it was for the other two areas. This reflects less economic activity and a different predominant activity in the northern area. Maximizing environmental quality by minimizing coliform bacteria count and BOD reduced benefits and increased cost in all areas. The environmental quality goals were met, subject to constraints of present economic activity and treatment methods. Improving the quality of the environment in terms of coliform bacteria and BOD beyond the levels shown in Appendix B, Table 4, could only be accomplished by removing people and industry from the basin.

6.2 Levels of Activities

The comparisons among areas along the Ashuelot River were limited to the rural, recreational, and intensive residential sectors because the urban and industrial sectors do not occur in more than one area each.

The optimum levels of selected activities by area are summarized in Table 6.1 for the objective of maximized net benefits and Table 6.2 for minimized public and private costs. In general, the activities run according to the resource constraints in the various areas, with no great surprises. It is interesting to note that the "no treatment" waste-water activities were more prevalent in the southern (downstream) area of the basin.

In the recreation sector, the consistent choice was between no treatment and public treatment of waste water. Individual septic tank treatment was not chosen in any situation, presumably because of the higher cost per household of this method.

The recreation cottage choices did not vary from area to area in any recognizable pattern, except that in the central and southern areas relatively more shore cottages were found than in the northern area for the relative lengths of shoreline. This fact may be due to the influence of Webster State Park, located in the northern area, which was constrained to have no shore cottages.

Differences between areas, but for the same objective maximized, were primarily due to differences in resources available and to the BOD-assimilative capacity of the river in the area. In general, more waste-water treatment and more effective waste-water treatment were required with the increased economic activity in the central and southern areas. This fact was more obvious when maximizing net benefits (REVOWAT) than when minimizing public and private cost (SOCCOST). Between areas, the incidence of cost shifted among economic units for both within objective optimized and between objectives. Rural household, intensive residential, and dairy farms were primarily affected. For farms, both the number of farms and farming practices were involved.

6.3 Shadow Price on BOD by Area

One indicator of the cost difference between areas appears in implied or shadow price on BOD. For the high river-flow level, BOD receives no shadow price in any area. In the northern area BOD is imputed no shadow price for median flow and 15 cents per pound for low-river flow (see Table 6.3). Compared to the central and southern areas, this represents a sizeable divergence. The central area receives a $0.56 per pound shadow price at median-river flow, and BOD discharge into the river at low flow exceeds assimilative capacity at C-classification. In the southern area, the pattern differs even more. When maximizing net benefits (REVOWAT), the shadow price on a pound of BOD increases from $0.56 per pound at median flow to $7.08 per pound at low flow. But when public and private costs (SOCCOST) are minimized, the shadow price increases from $0.107 per pound at median flow to $0.56 per pound at low flow.

6.4 Summary

The objectives optimized influenced economic activity in each area in a manner similar to their influence in the basin. Minimizing public and private cost and maximizing environmental quality (minimized coliform bacteria count

Table 6.1. Selected Optimum Activity Levels by Area, REVOWAT, Median Flow Current River Quality (BCC), Ashuelot River Basin

Activity	Units	Area		
		Northern	Central	Southern
Extensive residential				
No waste-water treatment	Households	7.	942.	953.
Individual septic tank waste-water treatment	Households	538.	192.	304.
Recreation				
No waste-water treatment	Households	--	213.	31.
Public waste-water treatment	Households	1194.	3625.	1700.
Individual septic waste-water treatment	Households	--	--	--
Shore cottage				
With boat–50' lot (1)	1 cottage	103.	98.	101.
No boat–50' lot (2)	1 cottage	--	80.	49.
With boat–100' lot (3)	1 cottage	--	--	--
No boat–100' lot (4)	1 cottage	--	--	--
With boat–1 acre lot (5)	1 cottage	--	--	--
No boat–1 acre lot (6)	1 cottage	--	--	--
Non-shore cottage				
With boat	1 cottage	14.	--	--
No boat	1 cottage	1065.	3220.	1506.
Public beach facility	4 people	4440.	13880.	6300.
Swimmer use of surface water	1 swimmer	21450.	62680.	29070.
Public boat launching facility	1 boat	80.	46.	22.
Public park boat use	1 boat	50.	--	--
Private tenting facility	9.2 sites			
Lake access	(acres)	6.5	--	10.9
No lake access	(acres)	15.2	11.7	--
Park tenting facility	(acres)	2.2	--	--
Forest cutting activity				
1st year	Acres	805.	915.	1130.
2nd year	Acres	805.	915.	1130.
Additional surface water yield	Acre feet	16.9	19.2	23.7
Dairying				
Usual practices	Farms	5.0	--	--
Non-polluting practices	Farms	--	10.0	6.0
Intensive residential				
River-water supply	Mil. gal.	--	--	--
Lake-water supply	Mil. gal.	--	--	--
Groundwater supply	Households	--	2.2	9.54

Table 6.1. (Continued)

Activity	Units	Area		
		Northern	Central	Southern
ntensive residential (Continued)				
Number of households	Households	--	304.	1184.
Public treatment 90% effective	Lbs. BOD	--	4400.	17140.
Public treatment 80% effective	Lbs. BOD	--	--	--
Private septic tank	Households	--	--	--
No waste-water treatment	Households	--	--	--

Table 6.2. Selected Optimum Activity Levels by Area, for Minimum Public and Private Costs, Current River Quality (BCC), Median Flow, Ashuelot River Basin

Activity	Units	Area		
		Northern	Central	Southern
Extensive residential	Households			
No waste-water treatment	Households	7.	1040.	1257.
Individual septic tank waste-water treatment	Households	538.	94.	--
Recreation				
No waste-water treatment	Households	--	--	--
Public waste-water treatment	Households	1194.	318.	218.
Individual septic waste-water treatment	Households	--	--	--
Shore cottage				
With boat–50' lot (1)	1 cottage	103.	--	--
No boat–50' lot (2)	1 cottage	--	178.	--
With boat–100' lot (3)	1 cottage	--	--	--
No boat–100' lot (4)	1 cottage	--	--	--
With boat–1 acre lot (5)	1 cottage	--	--	--
No boat–1 acre lot (6)	1 cottage	--	--	150.
Non-shore cottage				
With boat	1 cottage	14.	29.	25.
No boat	1 cottage	1065.	108.	41.
Public beach facility	4 people	4440.	13880.	3970.
Swimmer use of surface water	1 swimmer	21450.	56510.	16880.
Public boat launching facility	1 boat	80.	46.	64.
Public park boat use	1 boat	50.	--	--
Private tenting facility	9.2 sites			
Lake access	(acres)	6.5	--	10.9
No lake access	(acres)	15.2	5.9	--
Park tenting facility	(acres)	1.09	--	--
Forest cutting activity				
1st year	Acres	805.	400.	300.
2nd year	Acres	805.	200.	150.
Additional surface water yield	Acre feet	16.9	8.0	6.0
Dairying				
Usual practices	Farms	5.0	--	--
Non-polluting practices	Farms	--	6.40	4.40
Intensive residential				
River-water supply	Mil. gal.	--	--	--
Lake-water supply	Mil. gal.	--	--	--
Groundwater supply	Mil. gal.	--	2.22	9.54

Table 6.2. (Continued)

Activity	Units	Area		
		Northern	Central	Southern
Intensive residential (Continued)				
Number of households	Households	--	304.	1184.
Public treatment 90% effective	lbs. BOD	--	4400.	--
Public treatment 80% effective	lbs. BOD	--	--	--
Private septic tank	Households	--	--	--
No waste water treatment	Households	--	--	1184.

Table 6.3. **Implicit or Shadow Price for BOD by Area, Two Objectives Optimized, Three River-Flow Levels, Current Water Quality (BCC), Ashuelot River Basin**

	Objective optimized					
	Net benefits			Public and private cost		
	Flow level			Flow level		
Area	High	Median	Low	High	Median	Low
	Dollars per pound BOD					
Northern	0.00	0.00	0.15	0.00	0.00	0.15
Central	0.00	0.56	[1]	0.00	0.56	[1]
Southern	0.00	0.56	7.08	0.00	0.107	0.56
Basin	0.00	0.56	7.08	0.00	0.109	0.56

[1] Infeasible

Maximized net benefits = REVOWAT

Minimized public and private cost = SOCCOST

and BOD) had a retarding effect on level of economic activity. The incidence of cost varied with river-flow level, area, and objective optimized. The frequency with which certain shadow prices for BOD occurred and the magnitude of the shadow prices at low-river flow suggest a common ground for coordinated basin-wide water planning.

PART VII. EFFECT OF RAISING RIVER-QUALITY STANDARDS IN CENTRAL AND SOUTHERN AREAS TO B-CLASSIFICATION LEVEL

Improving water quality has been a goal of the people of New Hampshire. During the late 1960's, the recommended use classification and quality standard for the central area of the Ashuelot River were raised from class C to class B (see Appendix D). In this analysis, the southern area was assumed to be reclassified B-class also.

The two water-quality characteristics important to this study were coliform bacteria and dissolved oxygen. The amount of coliform bacteria permissable in class-C water is not specified, and in class-B water the most probable number per 100 milliliters must not exceed 240. Not less than five parts per million of dissolved oxygen must be present in class-C waters. Dissolved oxygen must be present in amounts not less than 75 percent of saturation in class-B water. A major determinant of oxygen content in water is the amount of organic and other material whose decomposition uses oxygen. A measure of the amount of material causing drain on dissolved oxygen is termed biochemical oxygen demand (BOD). This BOD in a way is an inverse measure of oxygen presence.

In terms of river-water use, the reclassification added bathing to the list of recreational activities and use of water as public water supply. There is a rather dubious line dividing water use for public water supply. Good drinking water is obtainable from low-quality water sources with appropriate treatment.[1] Use of class-C water from the river was included as an alternative in the southern area. The central area was assumed to obtain its public water supply from portions of the river that were class B.

Although coliform bacteria count was not specified for class-C water, coliform bacteria counts used in this study were based on water-quality tests made by the new New Hampshire Water Supply and Pollution Control Commissions, in July 1967, at various points along the river.

7.1 Possibility of Attaining B-Class Status

With existing industrial and other economic activity, the possibility of attaining the B-class level of quality is a topic of concern. For the central and southern areas and including the entire basin, the feasible solutions were not obtained for B-class quality during low-flow months (see Table 7.1). The frequency of such low flows becomes most meaningful. In the 36 years from 1934 to 1969, such low river-flow months occurred only six times.

At the August median-river flow, the basin taken as a whole could carry the economic activity currently found in the basin, with room for economic expansion. When areas were analyzed separately, BOD loadings again exceeded permissible poundage of BOD. It appears that meeting the B classification at median flow is possible but that coordination of water management among the areas and sectors is essential. River-flow level limited the potential level of economic development but not the classification level. Under the three flow levels used in this study, treatment processes were available for meeting industrial expansion potential if the classification level could be met.

[1] Kneese, A. V., and Bower, B. T. *Managing Water Quality: Economics, Technology, Institutions.* Baltimore, The John Hopkins Press, 1968.

Table 7.1. **Minimum BOD Attainable as Determined by Linear Programming Solution and Allowable BOD Loading of the Ashuelot River for Three Flow Levels and Two River Water-Quality Classifications.**

Area	Minimum BOD[1]	Constraint on BOD BCC class High	Constraint on BOD BCC class Median	Constraint on BOD BCC class Low	Constraint on BOD BBB class High	Constraint on BOD BBB class Median	Constraint on BOD BBB class Low
				Pounds BOD			
Northern	3,977	54,025	13,395	4,777	54,025	13,394.8	4,777
Central	16,694	155,250	32,746	9,216	46,510	9,810	2,760
Southern	35,520	340,612	112,766	46,432	55,362	18,329	7,547
Basin	56,080	479,921	158,887	65,422	252,187	83,491	34,378

[1] Objective function minimized; data in this column indicate minimum BOD attainable under median river-flow conditions.

For the basin as a whole, the change in classification did not have as much influence on potential economic activity under median river-flow conditions as did the change in river flow from median to low flow. The imputed price for one pound of biochemical oxygen demand (BOD), at median-flow C-classification was $0.56; at median flow B-classification, $4.15; and for low-flow C-classification, $7.08.

7.2 Influence of Change in Classification on Cost

The reclassification of the Ashuelot River to B class obviously would have an effect on cost of providing water supply as well as waste-water treatment. Only a detailed economic engineering study would develop the exact cost of moving from actual conditions *now* found in the basin to those conditions which result in meeting B classification. Both capital and variable cost must be included, part of which would be borne by state and federal governments.

The variable cost of operation at the two levels of classification provided interesting insights into relative public and private costs of the two classes. The basic assumption is that current facilities are available for meeting class-C classification under two situations. The first of these assumes optional development based on optimizing net benefits (REVOWAT) and minimizing public and private cost for providing water supply and waste-water treatment at about the present economic level (SOCCOST).

The influence on cost, assuming maximized net benefits (REVOWAT), is shown in Table 7.2 for August median- and high-flow levels. At high-river flows, the variable cost would be $25,795 higher for class B than for class C. This is an 11 percent increase in variable operating costs. The increase is 20 percent at the median-flow level. (Movement from class C to class B with low-flow conditions could not be analyzed because, as previously stated, class B at low flow is infeasible).

Table 7.2. **Effect of Change in River Classification in Central and Southern Areas of Ashuelot River Basin from C Class to B Class on Variable Costs, High- and Median-River Flow, Based on Optimizing Net Benefits, Month of August.**

River classification	High flow	Median flow
	Dollars	
Public and private variable cost		
B class	260,540	295,836
C class	234,745	246,959
Difference	25,795	48,877
	Percentage	
Difference as a percent of C class	11	20

Maximized net benefits = REVOWAT

For minimizing cost of providing water supply and waste-water treatment (SOCCOST), the actual level of variable cost of treatment is less than the above, and the increase in cost of moving from class C to class B is about the same (see Table 7.3). The percentage increase is substantially higher, 29 percent for high river-flow level and 31 percent for median-flow level.

Table 7.3. **Effect of Change in River Classification in Central and Southern Areas of Ashuelot River Basin from C Class to B Class on Public and Private Variable Costs, High- and Median-River Flow, Based on Minimizing Public and Private Cost, Month of August**

River classification	High flow	High flow	Median flow
		Dollars	
Public and private variable costs			
B class		115,553	123,654
C class		89,857	94,577
Difference		25,696	29,077
		Percentage	
Difference as a percent of C class		29	31

Public and private costs = SOCCOST

7.3 Effect on Change in Classification on Resource Use and Imputed Prices

The major effect on the change in classification to B class is to shift the wastewater treatment facilities to more effective treatment processes. These shifts were similar to those caused by variation in river-flow level. Raising water-quality class is analogous to lowering the river-flow level. The same is true for imputed prices and resource allocation.

PART VIII. SENSITIVITY ANALYSIS

Sensitivity analysis has been associated with cost changes resulting from increasing the level of water quality. Kneese and Bower[1] indicate this to be an advantage of the Davis study of the Delaware Estuary. Costs associated with four different levels of dissolved oxygen are presented by Kneese and Bower.

Through the programming method employed, sensitivity analysis can be extended to cover implied prices, resource allocation, integration of basin areas, and change in river classification. Although the sensitivity information is not precise, general implications can be drawn from this type of information.

8.1 Administrative Organization and Coordination

Sensitivity to administrative structure has been encountered in previous parts of this report, particularly in the central and southern areas of the Ashuelot. The northern area will become more important in the integrating process as population increases and as resources become developed. Of major importance in the administrative structure is the achieving of the river classification of B level for the central and, possibly, the southern areas. Reaching this water quality as much as half the time (month of August) may be impossible without considerable integrated effort. This is indicated by the inability to obtain feasible solutions for the central and southern areas under low river-flow levels.

The shadow price on BOD in the basin is an indicator of the impact of integrated planning. These shadow prices for three flow levels and two quality levels are as follows:

		Implied Price Per Pound BOD	
River-Flow Level	Classification	Minimum Public and Private Costs	Net Benefits
High	C	$0.0	$0.0
Medium	C	0.109	0.56
Low	C	0.56	7.08
High	B	0.0	0.01
Medium	B	0.12	4.15
Low	B	Infeasible	

The cooperative efforts between communities and between industry and community are often in debate. Grounds for many sides of the debate can be found. For each of the three industries considered separately, public treatment of industrial waste water was an optimal solution at one or more flow levels and for both objectives of maximizing net benefits (REVOWAT) and minimizing public and private cost (SOCCOST). The grounds for differences in optimal

[1] Kneese, A. V., and Bower, B. T. *Managing Water Quality: Economics, Technology, Institutions.* Baltimore, The Johns Hopkins Press, 1968.

solution of the problem also have basis in river-flow level and river-quality classification. Coordinated effort for waste-water management among sectors and among areas in the basin has strong basis in economies to be gained. Equitable sharing of the incidence of cost could be worked out in a mutually advantageous dialog.

8.2 Price and Resource-Allocation Sensitivity for Lake Resources

Precipitation (river-flow level) has little influence on lake resources because lake depth is managed by dams. Constraints on waste-water discharge were such that nutrient pollution of lakes would not result in accelerated algal bloom.[1]

8.21 Implied Prices

The implied prices for shoreline, lake-surface, and conservation reserves were applicable over a fairly large variation in these items. Lake surface could be shrunk by half or expanded by one-sixth of 3,020 acres in the basin before the implied price would change. Shoreline and conservation reserve demonstrated even greater stability over the range of resource availability in the basin taken as a whole. In the northern area, vacation cottages and lake surface were sensitive to price changes. A small percentage change in benefits accruing to cottage owners would result in a change in type of cottage owned. The two sensitive areas, cottages and lake surface, were related by boat-use practices of the cottage owners.

Regarding total number of vacation cottages in an area, sizeable price increases were required for expansion in number and lot size.

Other lake-use activities, such as day beach use, were not affected by relatively small percentage changes in prices associated with these uses–50 to 100 percent change in prices would be required. The number of participants might change with a change in price and would depend on the supply and demand situation in the area. It would appear that some experimentation with varying prices of day users and campers would be desirable and would lead to increased revenue and, in some cases, to regulated boat usage and beach crowding.

8.3 Sensitivity for River-Related Resources and Resource Use

The sensitivity of resource use and implied prices in the basin was related to variation in river-flow level and quality classification status of the river.

8.31 Resource–Use Sensitivity and River-Flow Level

When river flow was low, both number of farms were reduced and farming practices altered to reduce the amount of materials washing from farmland. Forest practices were unaltered by flow level.

In the rural residential, intensive residential and urban sectors, the most noticeable variation was concerned with waste-water treatment. Treatment pro-

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[1] For an analysis of lake water through a season, see Ching, C. T. K., and Frick, G. E. *Economic Effects of Pawtuckaway State Park: Effect of Park Use on Environmental Quality*. Durham, New Hampshire: University of New Hampshire, Water Resources Research Center, 1972, Research Report No. 6.

cesses moved to increasingly more effective treatments as flow level decreased. At low-flow level, the water supply source for the intensive residential and urban sector shifted from ground to river source, so that treatment processes could be used for improving river quality.

Resource allocation in the industrial sector was more varied and involved changing production technology as well as waste-water treatment process. Public treatment processes were frequently used. Although a large number of private waste-water disposal alternatives were considered, few individual methods were included in the optimal solutions. In paper production, only two private treatments were included in an optimum solution; there were only two in the wool industry; and there were two in the tanning industry.

8.32 Sensitivity of BOD Shadow Price

The shadow or implied price of BOD was sensitive to BOD loading of the river. Because of the numerous alternatives, it would change for relatively small changes in river loading. River-flow level had the major influence on the BOD shadow price. The flow level determined the amount of BOD loading.

8.33 Sensitivity to Price Change

A change in price of a processing technique may have more influence on optimal allocation in a totally different industry or sector. This influence is always present in problems of resource-use coordination.

The price sensitivity of selected activities in river-related sectors is shown in Table 8.1. The information in Table 8.1 is based on current quality constraints (BCC) for the August median-flow level and optimizing net benefits (REVOWAT).

Resource use in the forest sector did not change, due to small changes in prices of the activity. Activity in rural household, agriculture, intensive residential, urban, and the industrial sectors was more sensitive to small changes in price. As river-flow level increased, the resource use became more sensitive to price changes. At the low-flow level, there were fewer alternatives that met the required degree of treatment imposed by the river-quality classification.

In wool production, small reduction (10 percent or less) in price would result in a change in technology used at median-river flow levels. A decline in price of \$350.41 from the \$12,220 model price was required. This is about a 3 percent price change. A similar pattern emerged for the paper industry but not for the tanning industry. In the tanning industry, price sensitivity is found in waste-water treatment process. The price stability range in tanning waste-water treatment process was relatively large. This implies that a small price change would result in a change in activity level but a greater than ten percent change would be required for a second activity-level change. The reason for this sensitivity in tanning waste-water treatment may be due to the substitutes in the alternative treatment process. They were all either trickling filtration or activated sludge methods.

Public treatment of industrial waste water was employed by all industries at the median-flow level, and the stability range in price of these activities was relatively large (greater than 10 percent) in each case.

Table 8.1. Price Sensitivity: Model Price, Change in Price Required for a Decrease or Increase in Activity Level, Median River-Flow Level, Optimization of Net Benefits, Current River Quality, (BCC) Ashuelot River Basin

Item	Unit	Model Price	Median Flow: Change in price required for chg. in activity level: Decrease	Median Flow: Change in price required for chg. in activity level: Increase	Median Flow: Stable Range
			Dollars		
Rural household					
Waste water discharge, no treatment	Household	0.0	3.30	2.40	5.70[2]
Septic tank waste-water treatment	Household	-8.13	2.40	3.30	5.70
Forest harvest					
Second year after cut	Acres	+73.50	73.47	∞	∞
First year after cut	Acres	+73.50	73.49	∞	∞
Dairy farm					
Usual practices	64 animal units	+1300.00	xx	xx	xx[1]
Following nonpolluting practices	64 animal units	+1220.00	34.22	∞	∞
Intensive residential area					
River-water source	Million gallons	-589.00	7.55	15.30	22.85[2]
Groundwater source	Million gallons	-611.00	39.78	26.44	66.22
Public waste-water treatment (activated sludge)	Pounds BOD	-0.1296	.064	.494	.558
Private waste-water treatment (septic tank)	Households	-8.13	xx	xx	xx
No treatment of waste water	Households	0.0	xx	xx	xx

Table 8.1. (Continued)

Item	Unit	Model Price	Median Flow: Change in price required for chg. in activity level: Decrease	Median Flow: Change in price required for chg. in activity level: Increase	Median Flow: Stable Range
			Dollars		
Urban					
River-water supply source	Million gallons	-347.00	11.15	68.99	80.14
Lake-water supply source	Million gallons	-347.00	∞	11.16	∞
Groundwater supply source	Million gallons	-360.00	68.99	∞	∞
Water-supply treatment	Million gallons	-92.90	∞	72.88	∞
Sewage treatment 90% effective	Pounds BOD	-.072	0.044	0.128	0.172
Sewage treatment 80% effective	Pounds BOD	-.060	xx	xx	xx
Paper production:					
New technology	2.25 tons	+1207.14	17.11	∞	∞
Waste-water treatment sedimentation primary and irrigation secondary	New technology	-14.76	xx	xx	xx
Public treatment:					
90% effective	Present tech.	-14.40	15.94	11.25	27.19[2]
90% effective	New technology	-14.40	15.94	∞	∞
Wool production:					
Old technology	1000 lbs. wool	+1382.40	∞	305.07	∞[2]
New technology	8840 lbs. wool	+12220.00	350.41	∞	∞
Public waste-water treatment:					
90% effective	New technology	-32.40	19.92	∞	∞

Table 8.1 (Continued)

Item	Unit	Model Price	Median Flow: Change in price required for chg. in activity level		
			Decrease	Increase	Stable Range
			Dollars		
Tanning production:					
New technology	1 hide	+2.50	0.22	∞	∞
Waste-water treatment:					
Trickling filtration	New technology	- .708	.041	.363	.404
Activated sludge	New technology	- .985	xx	xx	xx
Public treatment:					
90% effective	New technology	- .384	.204	.041	.245

[1] xx not in basis

[2] in basis at 0 level

PART IX. COMPARISON WITH COASTAL WATERSHED, THE LAMPREY RIVER BASIN

For purposes of extending the analysis, the Lamprey River basin, in southeastern New Hampshire, was analyzed and the results compared with the Ashuelot River basin. The Lamprey drainage area in many ways is similar to the Ashuelot.

9.1 Description of the Lamprey River Basin

In the headwaters of the river and its tributaries, streams and both natural and artificial lakes are currently used primarily for recreational purposes. The Lamprey River basin contains a sizeable state park, Pawtuckaway State Park. Two small manufacturing and residential communities are located on the Lamprey about halfway from the headwaters to the confluence with Great Bay. One small leather processing plant was located near these two communities. The major residential areas are now located in the eastern portion of the river. The town of Durham, the location of the University of New Hampshire, has installed water-transfer facilities out of the basin to augment the water supplies now drawn from the Oyster River. At the fall line of the Lamprey, the town of Newmarket remains as a viable residential and manufacturing community. The Lamprey River basin is roughly two-thirds the size of the Ashuelot in terms of area

Artificial lakes were created more than 100 years ago for flow regulation of the Lamprey River. Manufacturing and hydroelectric power generation required a steady water supply throughout the year, particularly during periods of low, natural river flow. Since 1952, unregulated flow became evident as manufacturing and hydroelectric power was abandoned. Stream-flow levels reflect natural flow or unregulated flow only since 1952. Due to drought years in the mid-1960's, the median flow for the month of August was 705 million gallons. During the pre-1952 years with regulated flow, the monthly flow was consistently three to four times this amount. The maintenance of the lake level for recreation purposes came at the expense of river-flow regulation. The historic trade-off was recreational uses for manufacturing and power uses of impounded water. The trade-off, with the rapid growth in population in the eastern basin area, may turn out to be potable water supplies versus recreational uses.

9.2 Resource-Use Pattern and Implied Prices

The pattern of resource use and resource evaluation obtained in analysis was similar for both the Ashuelot and Lamprey River basins for median-flow condition. Strong conclusions should not be drawn from these likenesses. Both the Ashuelot and the Lamprey have stretches of rather slow moving, pond-like areas and other stretches which are rapidly flowing. This fact would have a major impact on recreation use of waters and waste-water assimilative capacity. Distribution of economic activity along the river would cause differences between river basins. Because the same basic model prices and coefficients were used for both rivers, similarity is to be expected. Of particular note, some untreated waste-water discharge from residences directly into the river was optimal for both rivers under many circumstances. From the analysis, and from our observation, we conclude that the Ashuelot is a more intensively used river for waste discharge.

9.3 Shifts in Lake-Resource Use

Industrial water use declined after World War II, and flow-regulating lakes in the Lamprey River basin were subsequently shifted to recreational uses. As indicated previously, stabilized recreational lake-water levels resulted in loss of a stream-flow regulation and considerable reduction in dry-month river-water yield.

Lakes in both watersheds are under development pressures. The super-highway system places the Ashuelot basin within commuting distance from expanding Connecticut River valley development in Massachusetts and Connecticut. The Lamprey area is under pressure from expanding local population as well as expanding population in northeastern Massachusetts. The values developed for the Ashuelot would appear applicable to the lake resources of the Lamprey River basin.

There is at least one exception. The Ashuelot area may not be facing a critical potable water supply problem for its expanding population and industry. In contrast, the southeastern New Hampshire expanding population may face such a crisis in the next half century.[1] The reallocation from the low-flow augmenting features of the Lamprey River basin lakes to recreational purposes may have a large price. With 1,487 recreational acres valued at around $10,000 to $15,000 per acre and 1,675 lake-surface acres valued at $100 to $150 per acre, the cost of reversing the use of the lakes could easily amount to more than $15 million and might even be three or more times that amount if capital structures are included. The cost of reallocating the use of these lakes may not only be economically prohibitive but also politically infeasible.

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[1]See New Hampshire Office of State Planning. *Public Water Supply Study, Phase One Report* and *Public Water Supply Study, Phase Two Report.* Concord, New Hampshire: Office of State Planning, 1968.

PART X. PROJECTED RESOURCE-USE PATTERNS AND IMPLIED PRICES, 1980.

The projected resource-use pattern and implied prices to 1980 were based on population increase and increases in the industrial water use in the central area. Projected water-supply needs and a plan for providing those needs through the year 2020 were completed in March 1972.[1] Population projections used here are based on the phase one report of this study and modified to reflect more recent change in growth patterns.

10.1 Population Projection

There are three areas of population growth. These are rural residences, intensive residential, and urban. Because only a part of each community was usually included in the watershed, the population projection by township was based on town growth prorated for the proportion of the community located in the Ashuelot watershed. The percentage increase in population over all types of areas was in the neighborhood of 17 percent but ranged from townships with virtually no growth to townships with as high as 25 or more percent growth. The projected increase in population is shown on Table 10.1.

10.2 Projection of Industrial and Recreational Water Use

Industrial water use in Keene was projected to increase by 10 percent from 1970 to 1980. Industrial and recreational water uses in areas outside Keene were determined by optimization of the model.

10.3 Other Projection Considerations

Since the entire Ashuelot River may be classified as B, only B-level constraints were used in the projection. The projections were limited to median and high, August river-flow conditions. Under low-river flow, the basin cannot reach the B classification with 1970 demands and with technology employed in the study.

Of major importance, these projections were based on current prices. A factor for inflation can be built into the analysis or applied to results. One of the major problems in using projected prices is the inability to project individual prices accurately. Some prices rise at different rates than others. This causes a change in price ratio, and the change in price ratio may be large enough to cause major shifts in resource use. The projections presented here are based on the assumption that current firms will stay in business over the period and that no change in price ratio will occur.

The assumption of no change in price ratios violates results developed within this study. Implicit prices in the recreation sector indicate economic pressures which will result in price-ratio changes.

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[1] See New Hampshire Office of State Planning. *Public Water Supply Study, Phase One Report* and *Public Water Supply Study, Phase Two Report.* Concord, New Hampshire: Office of State Planning.

Table 10.1 Population in the Ashuelot River Basin in 1970 with Projection to 1980.

Type of area	Unit	Population 1970	Population 1980	% increase 1970 to 1980
Rural residence	Household[1]	2,936	3,469	18
Intensive residential	Household[1]	1,488	1,786	20
Urban	Household[1]	5,000	5,750	15

[1] Average household size was 4 people.

Economic forces not confined to the river basin may have profound effects on the basin. A shift in market forces may result in loss of an industrial firm. The network of superhighways opens new alternatives for resource use. A shift in the industrial base from water-based manufacturing would have a sizeable effect on water demands and may be the most unpredictable factor of all. Increase in water-based industry in the basin is less likely to occur, due to present pressures placed on the existing water supplies and to the raising of the river classification to the B class. A major projection of the area economy to include industry, recreation, change in price ratio, and expansion of higher education facilities is beyond the scope of this study. Taking into account the problems with projections, some meaningful statement can be based on the simplified assumptions noted above.

Technology considered in planning will determine alternatives and costs. Stream, lake, and pond aeration devices, for example, were not considered in this analysis. Use of aeration devices on lakes is limited or prohibited on many water bodies in New Hampshire by institution arrangements. Such institutional limitation may prove to be costly. Artificial aeration and heating of lagoons is another alternative, but little is known about this kind of waste-water treatment process.

New impoundments are now being planned for providing adequate water supply for Keene. The data for this were not included in the projection because the operation of the system is scheduled for some time after 1980.

10.4 Shifts from Present Resource Use to Future Resource Use

Shifts in resource use must occur in identifiable steps. From the present situation with less than potential production and modest waste-water treatment plants, the first step would entail installation of adequate waste-water treatment facilities. This first step is most noteworthy because it involves sizeable capital investments and operating costs without added revenue to the area. To build this into the planning process is a major endeavor. To make the first step more palatable, it could be taken up in conjunction with industrial expansion and population growth planning, in such a manner that the benefits would accrue to cover some of the increased cost.

[1] Bevens, M. L. "The Campground Industry–Surging '60's, Sinking '70's?" in *Vermont Farm and Science.* Burlington, Vermont: University of Vermont Extension Service and Experiment Station, Spring 1972.

10.5 Projected Lake- and Related Land-Resource Use and Implied Prices

Lake and related recreational-land resource use is separated by dams from river resources. When these bodies of water are used for recreational use, they are employed in the highest value use. An alternative is their use for low-flow augmentation, and even then their value for low-flow augmentation is usually low.

Due to the separation of lakes from the central river and the above industrial assumption, projected lake-resource use will probably focus on more shore and non-shore cottages and more beach day-use facilities with less or perhaps no undeveloped shoreline. Price of lots, with or without cottages, will rise as will prices of day-use and camping facilities. The increase in prices may not be proportional and will reflect demand for each kind of resource use, with an accompanying change in price ratio. Bevens[1] suggests a doubling of camping fees, with prices rising to $5 to $8 per camping day.

Shoreline, surface water, and the recreational area will become increasingly used. The economic pressures are for development of many small-lot units. The picture will be one of a body of water surrounded by a housing development about one city block deep, with all the problems of a city block, including the usual urban water-facility needs. The development found on many lakes support this *city block* view of development.

10.6 Projected River-Related Resource Use and Implied Prices

The influence of moving from 1970 population to 1980 projected population on resource use is described in Table 10.2. The river-quality classification for the two comparison years was B level for median-river flow. The increase in population is accompanied by an increase in water demand and waste-water disposal activity.

It is interesting to note the relatively modest net increases in public waste-water treatment facilities called for in the optimal 1980 solution. This is for two primary reasons. First, the 1970 solution is so tightly constrained that there is relatively little untreated waste water permitted to enter the river, hence, there is little room left for expansion. Second, the assumption of 100 percent effectiveness of individual septic tanks was recognized in the 1980 solution as a means of further reducing BOD discharge to the river. This assumption requires closer scrutiny, particularly in the intensive residential areas.

Forest cuttings were unaffected as were number of dairy farms, which for both years were held to the minimum now in the basin. Manufacturing activity was unaffected between the two years for B-quality classification.

The two main influences on water-related resource use were a shift in waste-water treatment. More intensive residential houses were on private, septic tank waste-water disposal systems; more than 800 of these were shifted to more effective but more costly methods. The shift in waste-water treatment, mainly confined to residential houses, left the shadow price per pound of BOD at $4.15 for both years. Some 9 to 10 million more gallons of water were handled per month.

With an objective of minimizing the public and private cost of providing water supply and waste-water treatment for present economic activity, a slightly different picture emerged. More water passed through the system, even though fewer differences in treatment processes were found. The shadow price of BOD increased from $0.12 per pound in 1970 to $0.146 per pound in 1980.

10.7 High and Low River-Flow Months

Level of river flow is most important in any consideration of water-quality management. Periods of high-river flow provide poor guidelines because the assimilative capacity of the river is greatly increased. What has been called high flow occurs less than 90 percent of the time for the month of August, and it is 3 to 4 times the median flow. For best guidelines in managing water quality, some combination of median flow and low flow would provide the best results. What is called low flow occurs 10 percent or less of the time for the low-flow month August. Planning for the low-river flow for low-flow months may be very expensive and B-class classification may be difficult to attain. B-class in low-river-flow months is impossible to attain with the technology assumed in this study.

Table 10.2. Selected River-Resource Uses for Optimized Net Benefits, Median Flow, River Quality B Class (BBB), Ashuelot River Basin, 1970 and 1980

Item	Units	Year 1970	Year 1980
Rural households			
Waste-water discharge treated septic tank	Households	2,963	3,469
Waste-water discharge not treated	Households	0	0
Forest and agriculture			
First-year cutting	Acres	2,650	2,650
Second-year cutting	Acres	2,850	2,850
Dairy farms high level of pollutant-abatement practice	Number farms	12	12
Intensive residential			
Water source, ground	Million gallons	11.76	13.94
Waste-water discharge			
A public treatment	Households	1,291	412
A private treatment septic tank	Households	197	1,374
Urban			
Water source			
Lake	Million gallons	5.00	5.00
River	Million gallons	3.82	11.85
Ground	Million gallons	50.00	50.00
Waste-water discharge			
Activated sludge (90% effective)	Lbs. BOD removed	99,657	113,250
Trickling filtration (80% effective)	Lbs. BOD removed	0	0
Industrial			
Paper production–new process	Tons	2,090	2,090
Wool production–new process	Lbs.	691,600	691,641
Tanning production–new process	Number of hides	96,017	96,017
BOD transfer from industry to river			
Paper	Lbs. BOD	18,664	18,664
Wool	Lbs. BOD	4,555	3,671
Tanning	Lbs. BOD	21,123	21,123

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APPENDIX A

DATA SOURCES AND DATA MANAGEMENT

A. DATA SOURCES AND DATA MANAGEMENT

A.1 Population and Cultural Features

Data for population, number of household units, and recreation facilities were updated to the year 1970 from highway maps and geological survey maps by use of the Census of Population. Population projections were based upon the *Public Water Supply Study, Phase I,* done for the Department of Resources and Economic Development by Anderson, Nicholas, Inc. Data from this study also provided an atlas of information concerning water-supply sources and water use. Data were modified for individual cities and communities on the basis of engineering studies conducted under the auspices of the city of Keene and the State Water Supply and Pollution Control Commission.

Further adjustment in data was made for programming convenience. For example, suspended solids and biochemical oxygen demand (BOD) were converted to total pounds in the water rather than parts per million.

New Hampshire State Highway maps and U.S. Geological Survey maps were the basis of cultural features and areas of different kinds of land use and water bodies. The cultural features were updated from maps, based upon proportionate increases in population, discussion with County Extension workers, inspection of state timber tax records, and the Census of Water Works Utilities. These data were further checked against organized community and utility records and through personal inspection of the area involved.

A.2 Precipitation and Runoff

Precipitation was reflected in the model by actual surface-water runoff. Runoff data were obtained from *Water Resource Data for Massachusetts, New Hampshire, Rhode Island and Vermont, Part I, Surface Water Records, United States Department of Interior Geological Survey.* Actual data for quality of stream flow were obtained from records of the State Water Supply and Pollution Control Commission.

Overland surface-runoff quality from rural land was determined from information supplied in personal correspondence with Samuel Kunkle, then of the Agricultural Research Service (ARS), U.S. Department of Agriculture, on research conducted in northeastern Vermont, and which covered forest land use, agricultural land use, and rural village land use. Water-runoff quality for urban land use was developed from *Water Pollution Aspects of Urban Runoff,* Federal Water Pollution Control Administration, U.S. Department of the Interior, January 1969. Data on water quality and pollution effects from industry were developed from respective publications under the title "The Cost of Clean Water," published by the Federal Water Pollution Control Administration of the U.S. Department of the Interior.

The three main water-quality indicators used were coliform count, biochemical oxygen demand (as an indicator of dissolved oxygen), and suspended solids. The coliform count totals were based on m.p.n. (most probable number per 100 m.l.). The BOD total pounds estimates were based on five-day BOD measurements in parts per million. Suspended solids estimates were based on five-day BOD measurements in parts per million. Suspended solids estimates were expressed as total pounds in water and were developed from the industrial reports in "The Cost of Clean Water" series.

Even with simplifying assumptions such as dealing with coliform bacteria in terms of most probable number, important bacteria and virus detrimental features are glossed over. The most probable number count of coliform bacteria is and has been used as an indicator of presence of bacteria hazardous to health. However, the coliform number and pounds of BOD are most useful for integrating the large number of water-using activities into some simplified decision-making oriented model.

As disappointing as the omission of nitrate and phosphate nutrients is the lack of information on pollution effects of outboard motors. There are two features of boating use, one detrimental and one beneficial. The operation of a motorboat does two things: (1) it deposits engine wastes in the water body—this is detrimental—and (2) at the same time the swirling propellors and wave action resulting from outboard motors has an aeration factor for replacing dissolved oxygen in the water body.

A.3 Size of Lake Bodies and Shoreline Lengths

The size of water bodies was taken directly from the materials published by the New Hampshire State Planning Office, then under the Department of Resources and Economic Development, Concord, N.H. Lakes were assumed to have an average depth of 10 feet. Lakes in the model were aggregated into one big lake having so many square acres of surface water, so many acre-feet of water, and so much shoreline length. Lakes of the size of less than 10 acres were not included.

Lakes due to impoundments for flood-control purposes, such as the Surry Mountain Dam, by nature differ from other lakes and hence were treated as a different body of water of specified size, depth, and shoreline length.

A.4 Determination of Benefits Used in the Model

The determination of benefits related to water use is notoriously difficult to do. For many uses, there does not exist a per-unit price for some specific water use. However, for other uses, specific price or return data are available. These costs and prices were included in the respective activities in the model. Activities for the non-price benefits were included in the model, subject to valuation by the model.

Returns to water users and industries that influence water quality and quantity were based on the value-added concept. For agricultural purposes, the value added was developed from farm accounting service records. For industrial use, the value added was developed from the Census of Manufacturers for the state of New Hampshire. For recreational campground enterprises, estimates were obtained from *How to Plan the Recreation Enterprise,* Cooperative Extension Service, University of Maine, Orono, Maine, Circular 396, February 1968, by Francis E. Montville. For park and day use, charges at the nearest state park were used for pricing.

Vacation cottages provided one of the most difficult items to measure. For determining vacation cottage value, an indirect concept was used. The basic concept was as follows: the cost of owning a vacation cottage on a monthly (or annual) basis must equal or exceed the benefits derived from holding the vacation cottage; otherwise, no new cottage would be built, nor would the individual own the cottage. This value was determined from real estate transactions and listings in Strout Real Estate Catalog plus the annual tax computed on the full valuation of the cottage at a tax rate of $30 per thousand. The market value was amortized at 7 percent over a 20-year period.

A.5 Surface- and Ground-Water Supply Costs

The economics of groundwater versus surface-water supplies were compared by Arthur D. Jeffrey in *Economics of Water Supply in Rhode Island,* Agricultural Experiment Station, University of Rhode Island, Kingston, Rhode Island, Miscellaneous Publication 62, July 1966. H.H.H. Afifi and V.L. Bassie in *Water Pricing, Theory and Practice in Illinois,* Bureau of Economic and Business Research Bulletin Series No. 93, 1969, developed cost of water supply by source and size of utility. These two studies provide information on fixed and variable cost of water supply employed.

A.6 Waste-Water Treatment Cost

Data on the relevant industrial waste-treatment costs were taken from "The Cost of Clean Water" series, U.S. Department of the Interior, Federal Water Pollution Control Administration. These data were adjusted for time and location.

Data on variable cost for municipal water treatment were from *The Cost of Clean Water and its Economic Impact,* Vol. 1, 1969, Federal Water Pollution Control Administration, U.S. Department of the Interior, page 85. Fixed costs are from studies conducted in Illinois, adjusted by a time and location price index.

A.7 Interest Payments and Length of Loans

Interest rates were classified according to three uses. There were municipal or governmental bond issues, industry, and private consumer units. The interest rates employed were approximations under reasonable assumptions with regard to length of run and security of the borrower. The interest charges were as follows: government (local), 5 percent per annum; industrial firms, 6 percent; and private individuals, 7 percent.

In view of recent trends in interest rates and action of federal governmental agencies in money markets, these interest charges seem reasonable for the decision-making unit involved and over the time horizon that loans were usually made. Maturity of loan varied with type of structure.

A.8 Income Multipliers

Income multipliers were taken from "Estimated Impact of Military Cutbacks on a Regional Economy," by W. R. Henry and C. T. K. Ching, *Rhode Island Business Quarterly,* Volume 7, No. 3, September 1971, and based on income multipliers for the seacoast region of New Hampshire and Maine, 1964.

APPENDIX B

APPENDIX TABLES

Table 1. Abbreviated Name and Meaning of Objective Functions

Name of objective function	Meaning of items included
PRIBEN	Reflects minimum expenditure by (and opportunity cost) of owners and uses of water resources. Includes: 1. Water-based recreation home, tax and amortized value (interest and principal). Reflects minimum owner is willing to pay monthly to own recreation home. 2. Public park revenue (reflects willingness to pay).
PRODUCT	Returns (value added) to private enterprise. 1. Value added for farms, forests, water-based industry and private campground and private marinas.
PRITOT	PRIBEN + PRODUCT Combined benefits
PRICOST	Private cost of providing water supply and waste-water disposal. 1. Rural residence water expense (own well and septic tank). 2. Recreation water expense (same as 1). 3. Boat treatment of pollution, private treatment of boat pollution. 4. Village house-water expense: expense to village dwelling for providing own waste-water treatment (septic tank). 5. Industrial private water expense–as above.
PUBCOST	Public cost of providing water and waste-water disposal. 1. Recreation public treatment expense (recreation and campgrounds). 2. Boat pollution treatment expense. 3. Urban water-supply treatment expense. 4. Village water expense. 5. Industrial public water expense.
SOCCOST	PUBCOST and PRICOST = SOCCOST Combined cost in private and public sectors of providing portable water and waste-water disposal.
REVOWAT	PRITOT less SOCCOST = REVOWAT Net benefits to area.
PRINET	PRITOT less PRICOST = PRINET Net benefits to private sector.
ENVIRONMENTAL QUALITY	Minimum coliform bacteria count or pounds BOD.

Table 2. Model Name, Units, and Meaning of Annual Vectors

Name	Units	Meaning
Industrial sector		
LABPNT	Man years	Labor employed, year round. Calculated as a proportion of value added, based on 1967 Census of Manufacturers–does not account of differences in technology–included in production vectors–medium-sized plants only.
LABSEA	Man years	Labor employed, seasonal
VALAD	Dollars	Value added in production activity
VALADT	Dollars	Direct and indirect income effects (VALAD x respective multiplier 1967-68 prices).
ANNH2O	Million gallons	Annual water use calculated on basis of plant technology included in production activity by plant technology.
Other Sectors		
LABPMT	Man years	Labor employed, year round
LABSEA	Man years	Labor employed, seasonal
LABTOT	Man years	Labor employed, year round and seasonal
VALAD	Dollars	Value added in production
VALADT	Dollars	Direct plus indirect income effects (VALAD x respective multiplier)
RDAYUSE	One person	Use of recreation facility, one day
ANNH2O	Million gallons	Annual water use

Table 3. Value of Functionals and Annual Impact by Optimized Objective Functions, Ashuelot River Basin

Functional and annual impact	Units	Optimized objective function REVOWAT MAX	PRITOT MAX	PRINET MAX	PRODUCT MAX	PRIBEN MAX
Functional for August						
REVOWAT	1000 dollars	4,161	4,032	4,153	3,153	2,917
PRITOT	1000 dollars	4,408	4,409	4,399	3,536	3,243
PRINET	1000 dollars	4,229	4,084	4,334	3,205	2,958
PRODUCT	1000 dollars	2,765	2,767	2,756	2,773	1,600
PRIBEN	1000 dollars	1,643	1,643	1,643	762	1,643
PUBCOST	1000 dollars	68.6	51.6	80.7	51.6	41.1
PRICOST	1000 dollars	187.4	325.4	164.8	331.0	284.8
SOCCOST	1000 dollars	247.0	377.0	245.5	382.6	325.9
Annual vectors						
VALADT	1000 dollars	52,242	52,275	52,065	52,310	29,629
LABTOT	Man-years	4,271	4,271	4,265	4,273	2,524
RDAYUSE	1000 people	9,575	9,575	9,575	3,241	9,575
ANNH2O	1 million gal.	3,480	3,537	3,480	3,541	2,589

[1] Median flow, B water-quality constraints in northern area, C quality in central and southern areas.

Functional and annual impact	Units	Optimized objective function				
		PUBCOST MIN	PRICOST MIN	SOCCOST MIN	BOD MIN	COLIFORM MIN
Functional for August						
REVOWAT	1000 dollars	2,041	1,970	2,028	1,735	2,056
PRITOT	1000 dollars	2,368	2,081	2,123	2,073	2,452
PRINET	1000 dollars	2,076	2,039	2,074	1,784	2,100
PRODUCT	1000 dollars	1,606	1,974	995	1,311	1,690
PRIBEN	1000 dollars	762	107.6	1,127	762	762
PUBCOST	1000 dollars	35.5	69.3	46.0	48.9	43.6
PRICOST	1000 dollars	291.2	42.3	48.6	289.1	352.5
SOCCOST	1000 dollars	326.8	111.6	94.6	338.0	396.1
Annual vectors						
VALADT	1000 dollars	29,659	36,941	18,543	24,609	31,608
LABTOT	Man-years	2,526	2,934	1,819	2,071	3,354
RDAYUSE	1000 people	3,239	411.6	6,233	3,239	3,239
ANNH2O	1 mil. gal.	2,593	2,364	2,136	2,374	3,550

Table 4. Objective Function Values For Five Optimized Functionals, August Median Flow, Current Water Quality (BCC), Ashuelot River Basin

Optimized Functional	REVOWAT (dollars)			PRITOT (dollars)			SOCCOST (dollars)		
	Northern	Central	Southern	Northern	Central	Southern	Northern	Central	Southern
REVOWAT	409,090	970,270	2.780×10^6	436,920	1.062×10^6	2.911×10^6	27,830	92,170	131,067
PRITOT	(1)	(1)	(1)	436,920	1.063×10^6	12.777×10^6	(1)	(1)	(1)
SOCCOST	409,090	669,199	1.094×10^6	436,920	718,446	1.131×10^6	27,830	49,247	37,429
Minimized BOD	142,352	367,815	1.282×10^6	182,178	536,132	1.422×10^6	39,826	168,317	139,961
Minimized Coliform	142,352	366,345	1.568×10^6	182,178	536,132	1.795×10^6	39,826	169,787	226,656

	BOD (pounds)			Coliform (billion organisms)			VALADT (dollars)		
	Northern	Central	Southern	Northern	Central	Southern	Northern	Central	Southern
REVOWAT	7,185	32,746	112,766	3,612	811,631	1.250×10^6	2.353×10^6	1.772×10^6	47.2×10^6
PRITOT	7,082	32,746	112,766	340	710,957	1.305×10^6	$2,353 \times 10^6$	2.743×10^6	103.3×10^6
SOCCOST	7,185	32,746	112,766	3,612	859,100	2.005×10^6	2.353×10^6	628,836	17.187×10^6
Minimized BOD	3,977	16,694	35,521	142	337,809	816,710	433,925	968,051	23.203×10^6
Minimized Coliform	3,977	16,694	88,541	142	36,359	728,153	433,925	968,051	30.072×10^6

(1) Values not calculated.

APPENDIX C

CAPITAL AND FINANCE COSTS

APPENDIX C

Capital Cost and Financing

Capital cost or cost of plant, equipment, dams, and piping can be most elusive. Capital costs were developed for water-supply treatment plants and waste-water treatment plants, based on size as measured in human population equivalents. With the river basin taken as a whole, the possibility of joint community with community and with industry was desirable for minimizing cost and meeting river-water classification standards. The exact amount of combined activity possible is determined by topography in the area and distance between economic units.

Also, water-treatment plants with piping are already found in the basin. These plants would influence the decision arrived at by residents of the river basin and may involve non-monetary consideration. Another item that would influence decision regarding capital items would be the scheduling of construction. Financing arrangements for funding plant construction are borne by federal, state, and local government units. The cost to local residents of waste-water treatment plants can be reduced, through regional planning, from 10 percent of total cost to 5 percent. Federal funding also is subject to a variety of considerations.

These capital and financing costs were not considered in much detail because they would have little meaning as developed and would involve cost estimates for a large number of alternative combinations. Estimates of costs of water-treatment plants, piping, and equipment for most towns are available from one or more sources. The omission of capital cost and financing was based on these reasons and not because they are unimportant.

APPENDIX D

WATER-QUALITY STANDARDS
STATE OF NEW HAMPSHIRE

RECOMMENDED USE CLASSIFICATIONS[1] AND WATER QUALITY STANDARDS AS OF JANUARY 1, 1970
BASED ON CHAPTER 149 REVISED STATUTES ANNOTATED[2]
NEW HAMPSHIRE WATER SUPPLY AND POLLUTION CONTROL COMMISSION

	Class A	Class B	Class C	Class D
	Potentially acceptable for public water supply after disinfection. No discharge of sewage or other wastes. (Quality uniformly excellent).	Acceptable for bathing and recreation, fish habitat and public water supply after adequate treatment. No disposal of sewage or wastes unless adequately treated. (High aesthetic value).	Acceptable for recreational boating, fishing, and industrial water supply with or without treatment, depending on individual requirements. (Third highest quality).	Aesthetically acceptable. Suitable for certain industrial purposes, power and navigation. (Lowest allowable quality now less than ½ mile in entire state).
Dissolved Oxygen	Not less than 75% Sat.	Not less than 75% Sat.	Not less than 5 p.p.m.	Not less than 2 p.p.m.
Coliform Bacteria per 100 ml	Not more than 50	Not more than 240 in fresh water. Not more than 70 MPN in salt or brackish water.	Not specified	Not specified
pH	Natural	6.5 – 8.0	6.0 – 8.5	Not specified
Substances potentially toxic	None	Not in toxic concentrations or combinations.	Not in toxic concentrations or combinations.	Not in toxic concentrations or combinations.
Sludge deposits	None	Not objectionable kinds or amounts.	Not objectionable kinds or amounts	Not objectionable kinds or amounts.
Oil and Grease	None	None	Not objectional kinds or amounts.	Not of unreasonable kind, quantity or duration.
Color	Not to exceed 15 units.	Not in objectionable amounts.	Not in objectionable amounts.	Not of unreasonable kind, quantity or duration.
Turbidity	Not to exceed 5 units.	Not to exceed 10 units in trout water. Not to exceed 25 units in non-trout water.	Not to exceed 10 units in trout water. Not to exceed 25 units in non-trout water.	Not of unreasonable kind, quantity or duration.
Slick, Odors and surface-floating Solids	None	None	Not in objectionable kinds or amounts.	Not of unreasonable kind, quantity or duration.
Temperature	No artificial rise	NHF&GD, NEIWPCC, or NTAC-DI – whichever provides most effective control.[3]	NHF&GD, NEIWPCC or NTAC-DI – whichever provides most effective control.[3]	Shall not exceed 90°F.

Notes: [1] The waters in each classification shall satisfy all provisions of all lower classifications.
[2] For complete details see Chapter 149 RSA.

[3] NHF&GD = New Hampshire Fish and Game Department
NEIWPCC = New England Interstate Water Pollution Control Commission
NTAC-DI = National Technical Advisory Committee, Department of the Interior